East Engineering Library

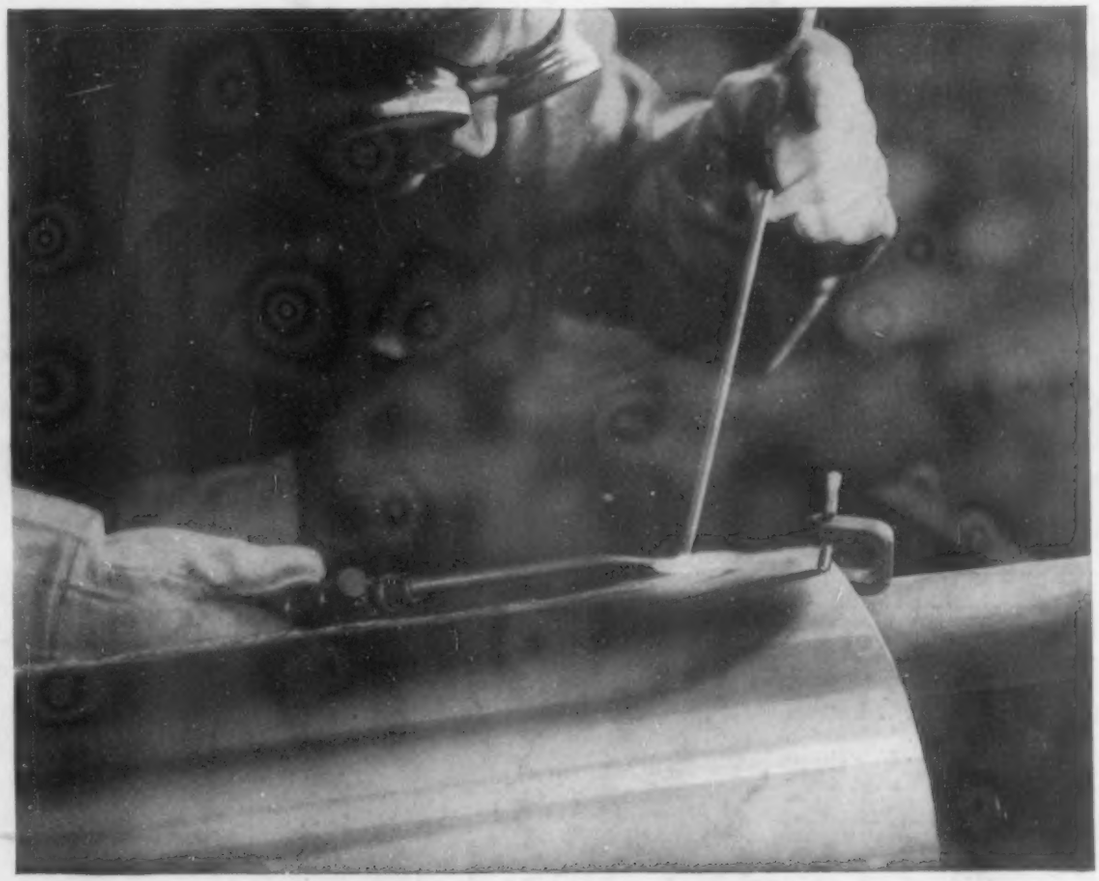
JAN 29 1936

IN TWO SECTIONS

SECTION ONE

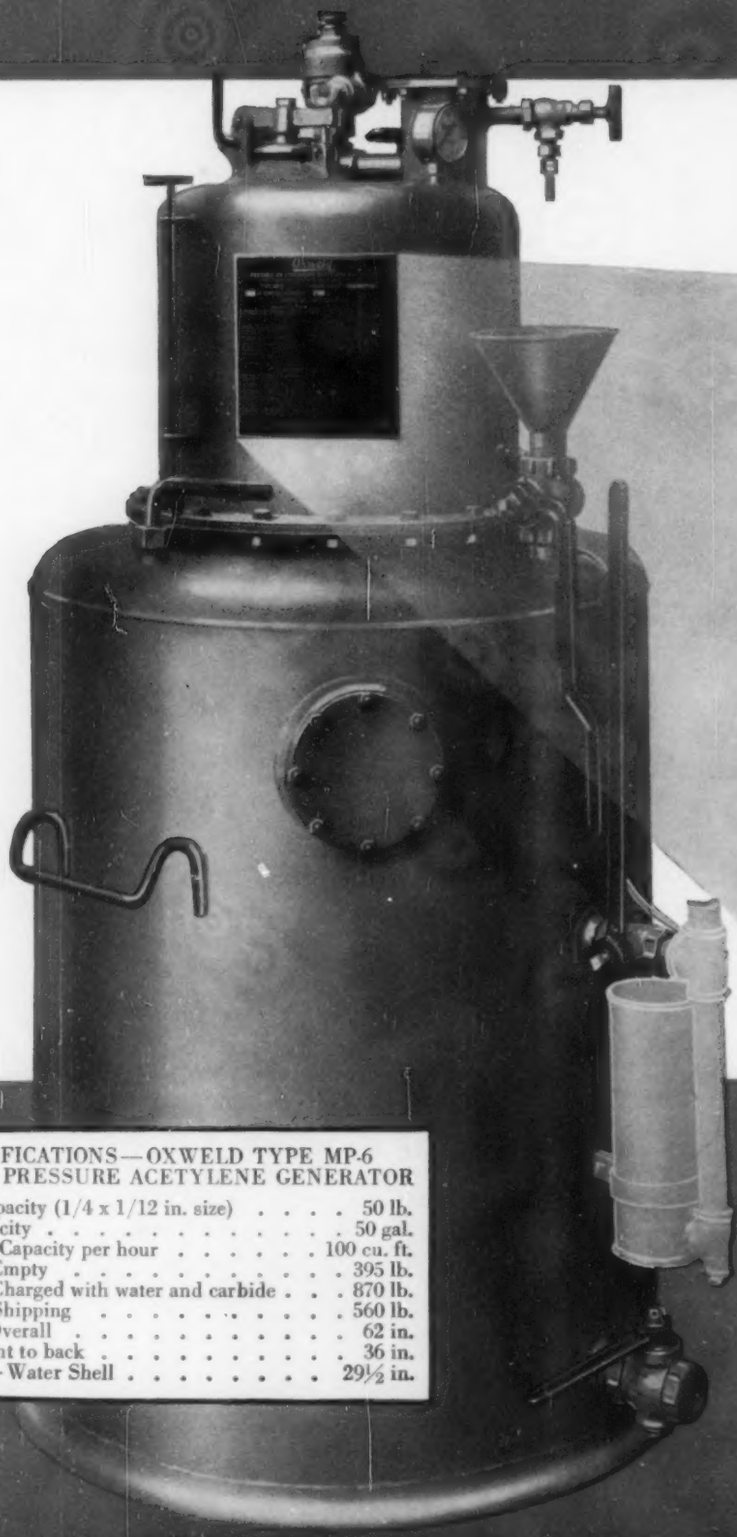
THE AMERICAN WELDING SOCIETY JOURNAL

VOLUME 15 JANUARY 1936 NUMBER 1



PUBLISHED MONTHLY FOR THE ADVANCEMENT OF THE SCIENCE AND ART OF WELDING

OXWELD QUALITY *at a new low pri*



Oxweld

PORTABLE AND STATIONARY ACETYLENE GENERATOR TYPE MP

1. Fully housed in welded steel, the MP-6 is unusually rugged.
2. Automatic gravity feed mechanism in dome assures uniform pressure.
3. Pressure is adjustable to 14 lb. per sq. in. No additional regulator is necessary.
4. The MP-6 is adaptable to stationary or portable requirements and to all types of blowpipes.
5. It insures continuous efficiency and economy in service.

*Examined and Listed by Underwriters' Labora

SPECIFICATIONS—OXWELD TYPE MP-6 MEDIUM PRESSURE ACETYLENE GENERATOR

Carbide Capacity (1/4 x 1/12 in. size)	50 lb.
Water Capacity	50 gal.
Generating Capacity per hour	100 cu. ft.
Weight — Empty	395 lb.
Weight — Charged with water and carbide	870 lb.
Weight — Shipping	560 lb.
Height — Overall	62 in.
Length, front to back	36 in.
Diameter — Water Shell	29½ in.

● Many of the advanced feature MP-6 were never before included but the larger sizes of Oxweld gen

You will want to study these feat notice how well this generator is maximum efficiency in handling Any Purox or Prest-O-Weld jobber office will furnish complete details. The Linde Air Products Company Union Carbide and Carbon Corpora

Everything for Oxy-Acetylene Welding and Cutti

LINDE OXYGEN • PREST-O-LITE ACETYLENE • OXWELD APPARATUS AND SUPPLIES

FROM PRODUCTS OF UNITS OF UCC UNION CARBIDE AND CARBON CORPORATION LINDE UNION C

THE
AMERICAN WELDING SOCIETY
JOURNAL

WM. SPRARAGEN, Editor | VOL. 15 | NO. 1

JANUARY

Contents

Technical Papers, Items and Reports

Page

A Tank Being Fabricated with the 18-8 Columbium-Treated Rod to Meet the Severe Requirements of the Chemical Industry (Courtesy Linde Air Products Company) ..... Frontispiece

Construction and Maintenance Problems Solved by Welding, by *A. F. Davis* 2

The Welding of the Alloy Steels, by *J. C. Hodge* 6

Welding and Cutting High Chromium Steels, by *W. J. Priestley* 14

Yoloy—Its Properties and Welding, by *Fred J. Esslinger* 18

Inspection of Welded Seams in Pressure Vessels, by *Wm. D. Halsey* 20

Arc Welding in Argon Gas, by *Gilbert E. Doan* and *William C. Schulte* 23

Tests to Determine the Feasibility of Welding the Steel Frames of Buildings for Complete Continuity, by *W. M. Wilson* 28

Current Welding Literature 38

Society and Related Activities

Welding Research Committee—Engineering Foundation 39

Translations of Important Foreign Articles 39

School Attracts Welding Engineers from Diverse Industries 39

Thermal Stresses in Welded Bars 40

Tentative Welding Program—A. I. E. E. Winter Convention 40

Employment Service Bulletin 40

Bound Volume Journal 40

American Institute of Steel Construction 40

Section Activities 40

American Welding Society Directors, 1935–36 41

ISSUED MONTHLY

AMERICAN WELDING SOCIETY

PUBLICATION OFFICE
20th and Northampton Sts.,
Easton, Pa.

EDITORIAL AND GENERAL OFFICES
33 West 39th St.,
New York, N. Y.

OFFICERS FOR 1935–36

President — J. J. Crowe
Treasurer — C. A. McCune
Senior Vice-President — E. R. Fish
Secretary — M. M. Kelly

Divisional Vice-Presidents
A. G. Leake, New York & New England
T. C. Smith, Pacific Coast
W. W. Reddie, Middle Eastern
C. L. Eksergian, Middle Western
E. E. Dillman, Southern Division

SECTION HEADQUARTERS

PHILADELPHIA
Engineers' Club, 1317 Spruce St.
CHICAGO
608 South Dearborn St.
PITTSBURGH
Room 906, House Building
NEW YORK
33 West Thirty-Ninth St.
NORTHERN NEW YORK
General Electric Co., Schenectady, N. Y.
CLEVELAND
410 Hanna Building
SAN FRANCISCO
Park Ave. & Halleck St., Emeryville, Cal.
LOS ANGELES
2423 East 58th Street
BOSTON
Engineering Societies of New England
715 Tremont Temple
WESTERN NEW YORK
500 Morgan Bldg., Buffalo, N. Y.
DETROIT
Paramount Welding Supply Co.
5950 Second Blvd.
PORTLAND, ORE.
P. O. Box 1899, Station F
MARYLAND
516 N. Charles Street
MILWAUKEE, WIS.
2841 N. 51st Street

The Society is not responsible for any statement made or opinion expressed in its publications. Permission is given to reprint any article after its date of publication, provided proper credit is given.

Copyright, 1936, by the American Welding Society

Subscription $4.00 per year in United States and possessions; $4.50 in Canada, Foreign Countries, $5.50.

Entered as second-class matter January 15, 1932, at the post-office at Easton, Pa., under the Act of March 3, 1879.

Construction and Maintenance Problems Solved by Welding

By A. F. DAVIS†

Electric Arc Constructs Large Tank for Treating Rice against Infestation

A large rectangular tank which is to serve as a chamber for treating rice against infestation, and which is entirely arc welded, was recently completed at the Birmingham, Alabama, plant of the Chicago Bridge & Iron Works for the Louisiana State Rice Milling Company at Abbeyville, Louisiana.

The accompanying illustration shows the treating chamber which is 50 feet long by 6 feet 6 inches wide by 6 feet high. The installation also includes an accumulator tank which is 2 feet 6 inches diameter by 18 feet. The thickness of plate in the treating chamber is $^3/_8$ inch and in the accumulator tank $^{17}/_{64}$ inch.

The tank has a designed operating pressure of 100 lb. per sq. in. The treating chamber is designed for $29^1/_2$ inches minimum vacuum.

A total of 1750 linear feet of welding was required in construction. Of this amount, 350 feet is $^3/_8$-inch bead, 1100 feet $^3/_{16}$-inch bead and 300 feet $^5/_{16}$-inch and $^1/_4$-inch beads.

The special treating service for which this tank is to be used utilizes the Guardite process, developed by the Guardite Corporation, Chicago. The Guardite process is a vacuum fumigation method of treating foodstuffs, tobaccos, furs, etc., against infestation. The products are placed in a treating chamber either in the raw-material stage or after completely packaged. The treating chamber is closed, a 29-inch vacuum is drawn on the chamber and a predetermined amount of gas admitted to the chamber.

The amount or dosage of gas depends upon the type of material which is to be treated and the length of the treating period. Ordinarily, an economical treating period is $2^1/_2$ to $3^1/_2$ hours as this permits a plant to handle two charges during the day and one at night. With an average treating period of three hours, the normal dosage is from 30 lb. to 40 lb. of gas per thousand cubic feet of treating chamber space.

The gas, which is a mixture of ethylene oxide and carbon dioxide, is shipped in cylinders under 800 lb. pressure. The gas is expanded to 75 lb. pressure in an accumulator tank and preheated to 120° F. to assure its entering the chamber in the form of a true gas.

The principal advantages of using a vacuum treating chamber instead of an atmospheric treating chamber are that the gas will penetrate the charge quickly and thoroughly and the lack of oxygen increases the rate of respiratory metabolism of the adult insects, rendering them more susceptible to the toxic effect of the gas.

The treatment kills all forms of infestation including the egg. This gives thorough protection as it prevents insects from hatching after food products leave the manufacturer's plant due to being stored in warm warehouses or coming in contact with the proper conditions for hatching insects on the retailers' shelves. This protection has two definite results. It reduces the amount of returned merchandise due to infestation and it reduces the loss of sales due to consumers finding merchandise in an infested condition.

Power Shovel

Time was when a power shovel's beauty resided almost wholly in its brawn. Not so today, however, as witness the unit shown in Fig. 2 built by Koehring Com-

Fig. 1—Large Rectangular Tank to Be Used in Treating Rice against Infestation, Recently Constructed Entirely by Arc Welding at the Birmingham, Alabama, Plant of the Chicago Bridge & Iron Works for the Louisiana State Rice Milling Co.

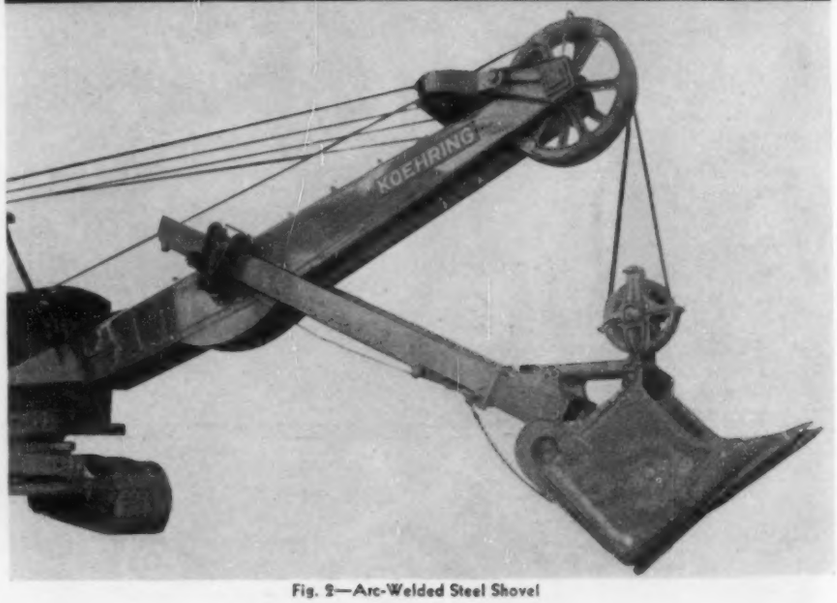


Fig. 2—Arc-Welded Steel Shovel

† Vice-President, Lincoln Electric Co.

Fig. 3—Hard Surfacing Worn Teeth

pany, Milwaukee, Wis. Constructed entirely of steel arc welded, this shovel boom has a smooth, even surface, unbroken by protruding connecting members. Yet its clean-limbed construction possesses greater strength per pound than that of brawnier-looking shovels.

Drag Line Bucket

On the "graveyard shift" during construction of the Colorado River Aqueduct, an arc welding operator climbs into the maw of a huge drag line bucket and applies new hard-steel biting surfaces to its worn teeth.

Welded Pipe Line

Over the hilly terrain near Palo Alto, California, this 22-inch arc-welded pipe line, scheduled for completion in December, will transport natural gas for the Pacific Gas and Electric Company. The line runs from Milpitas to San Francisco, a distance of approximately 45 miles. In its construction, the contractors, H. C. Price Inc., used the shielded arc welding process. The welding operator is shown making a "bell-hole" joint (Fig. 4).

Arc Welding Aids Construction of Fort Peck Dam

Construction of Fort Peck Dam, Montana, large Missouri River flood-control and navigation project, has progressed steadily during recent months. Here at Fort Peck, as at Grand Coulee, San Francisco–Oakland Bay bridge and other large engineering projects, operations are being aided considerably by the electric arc process of welding. At Fort Peck, arc welding has been found the most satisfactory method of building a steel core wall to prevent seepage through the dam's foundation.

This seepage-proof wall is necessary since the dam is being constructed by depositing dredged materials in such a way as to form a slope or beach toward the central portion of the dam.

Fig. 4—Making Bell Hole Weld

The steel wall is erected by welding steel sheet piling with the electric arc. (See Fig. 5.) This wall of steel acts not only as an impervious diaphragm but also provides a necessary bond between the foundation and the dam since it projects 20 feet into the latter. Figure 6 shows the pile driving crew at work. The diver in the photo is going down 13 feet under water to cut the steel piling with the electric arc. A total of 65 running feet of piling was cut in this way. The operator required no protective lens since the water was so muddy the arc was just barely visible. Arc welding has been found particularly effective in taking the slack out of steel piling after it has been filled. Extending the wall is also easily done by welding on additional sections of piling as required.

Fort Peck Dam is to serve as a storage for excess flood waters of the Missouri River, thus checking flood hazards. Releasing these stored waters during the period of low water will also provide navigable depths in the river below Sioux City.

Fort Peck Dam will have a maximum height of 242 feet above the river bed. Construction is by the hydraulic fill method and 100,000,000 cubic yards of material will be required. It is expected that before the 1935 working season ends, 20 per cent of the required volume will be in place. The dam is being built under supervision of the Corps of U. S. Army Engineers, as Project No. 30 under the 1933 PWA program.

New Drop Pit Table for Locomotive Maintenance Announced by Shaw Box Crane and Hoist Company

A special purpose electrically operated machine known as a drop pit table, which when installed at division point back shops or roundhouses, permits the economical maintenance of locomotives at these points rather than at the large main shops, is constructed entirely by arc welding by the Shaw Box Crane and Hoist Company, Inc., Division of Manning, Maxwell & Moore, Inc., Muskegon, Michigan.

The new welded unit (see Fig. 7) is built in both movable and stationary

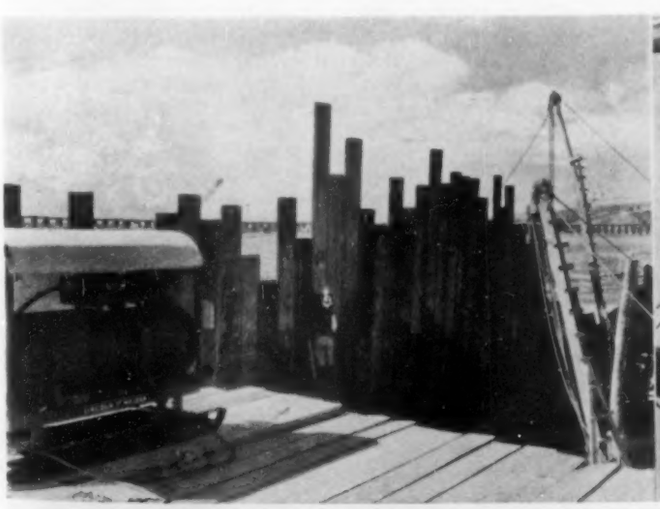


Fig. 5—Arc Welding Operator Working on the Steel Sheet Pile Core Wall Being Erected through the Center of Fort Peck Dam to Insure against Seepage through the Dam's Foundation

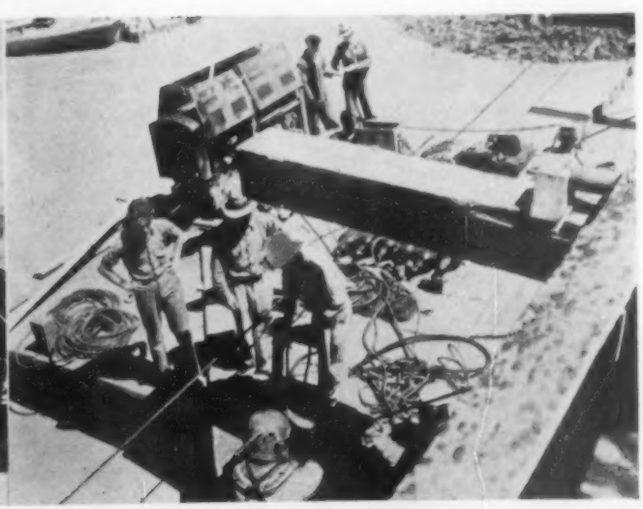
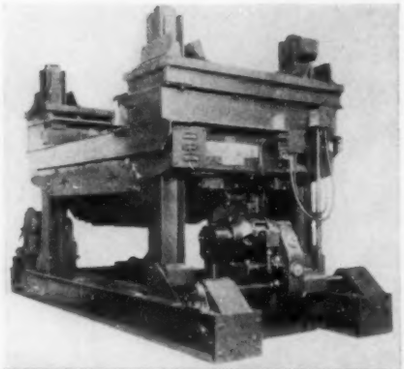


Fig. 6—Pile Driving Crew at Work Erecting a Core Wall of Steel Sheet Piling at Fort Peck Dam, Montana, on the Missouri River. Operations Are Carried on under Water as Indicated by the Diver on the Ladder



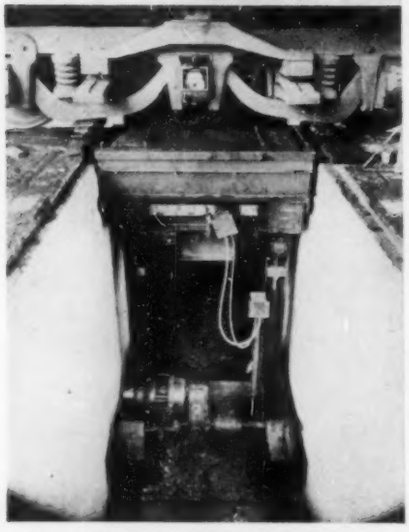


Fig. 7—Latest Type Drop Pit Table for Use in Locomotive and Car Shops for Removal and Replacement of Wheels and Trucks Is Entirely Arc Welded

Fig. 8—View of New Arc-Welded Drop Pit Table Installed at the Cincinnati Union Terminal, Cincinnati, Ohio

types for removing and replacing locomotive driving wheel sets, engine and trailer trucks.

Three independent units make up the complete table—the truck, lifting table and table top. The lifting table is raised and lowered between its rigid steel columns, mounted on the truck, by four drums and four flat steel flexible cables. The drums are operated simultaneously by one motor through two duplicate gear drives contained in the table. Hence, an equal pull is applied at each corner of the table. The columns support and guide the table. The table top is detachable and is equipped with locking bars and sections of rails to form a continuous track over the pit when locked in position (see Fig. 8).

The exclusive feature of the design of this drop pit table is the use of four flexible cables and winding drums for raising the load, rather than the former practice of using jack screws. This feature permits the raising or lowering of the load without spotting accurately on the table top.

The arc-welded construction of the drop pit table permits the many economies incident to the use of standard shapes, plate, etc. No castings are required. Bolts are used only to permit removal of certain parts.

As noted in Fig. 7, the unit is supported by four standard H-columns carried on and welded to a base composed of two H-columns welded integral with cross connecting members. Additional stiffness is provided the vertical columns by steel gusset plates welded to them and to the base. The lifting table is also fabricated by welding a number of separate parts including channels, H-columns, plate, angles, etc., into a single piece of steel.

The table is moved along its track on four wheels driven by gearing connected with an electric motor mounted on the base of the unit.

The use of arc welding in construction is reported to save approximately 15 per cent in weight. This weight saving is made possible by the elimination of intermediate connecting members and by use of materials which provide adequate strength without excessive weight. The savings made by arc welding in cost and time of construction can be appreciated from the fact that no patterns are required, that detailing is greatly reduced and that punching and drilling are entirely eliminated except where bolts are used to permit removal of certain parts.

Operating advantages claimed for the new arc welded drop pit table are as follows: It will not bind or stick when loading is unbalanced because it is designed for unbalanced loading and there is an equal pull at each corner of the table; the water nuisance generally prevalent in pits is eliminated because there are no guides to destroy water proofing in pit walls; the cost to maintain is low because all gearing operates in baths of oil in sealed enclosures; it is easy to maintain because all parts are accessible for inspection and lubrication; it is safe because it cannot be lowered except by power and table stops instantly when power is shut off; table is stopped by automatic stop when it reaches its highest or lowest position; control is by push-button; operation is dependable because all the parts which heretofore have caused tie-ups in drop pit table operation have been eliminated; there are no springs in the trucks to become fatigued and cause table to drag when traveling in the pit.

Electric Arc Completes Three Large Tanks a Month Ahead of Schedule

Record construction speed was recently made at Brooklyn, New York, when three 200,000-gallon rectangular bulk storage tanks were completed a full month ahead of schedule. These tanks, shown in accompanying illustrations, were built by the J. K. Welding Company of New York

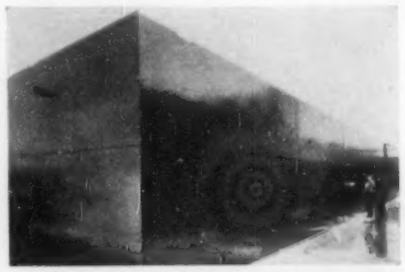


Fig. 9—Two of Three 200,000-Gallon Bulk Gasoline Storage Tanks Constructed Entirely by Shielded Arc Welding

City for the Colonial Beacon Oil Company, Inc., subsidiary of the Standard Oil Company (N. J.).

Each of the tanks is 60 feet long by 38 feet wide by 12 feet deep (see Fig. 9), and contains two compartments. A total of 241 tons of steel was required for construction. This was made up of 180 tons of steel plate, 60 tons of angles and 1 ton of fittings.

Construction was by the Truss-Weld patented system of framing developed by Johannes Kjestead, consulting welding engineer of New York City.

The shell of each tank is $^{3}/_{8}$-inch plate, reinforced by steel braces spaced on 2-foot centers each way. The horizontal braces are angles, $1^{1}/_{4}$ inch by $1^{1}/_{4}$ inch by $^{5}/_{16}$

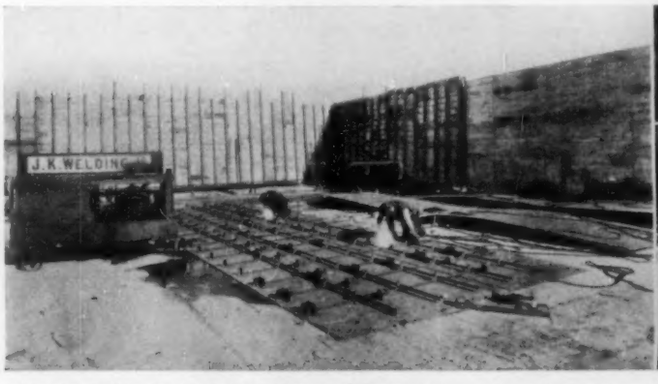


Fig. 10—Welding Jig Used in Assembling and Welding Trusses of Large Tanks to Insure Accurate Spacing and Alignment

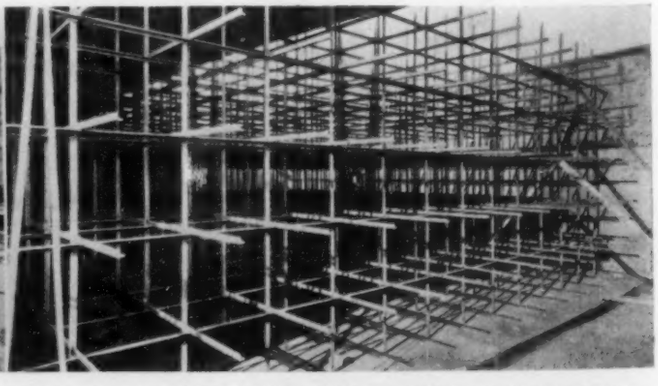


Fig. 11—View of Truss-Weld Patented System of Framing Used in Constructing All-Welded Bulk Storage Tanks

Fig. 12—Welding the Roof of 200,000-Gallon Bulk Storage Tank Showing Eleven Electric Arcs in Operation

Fig. 13—The Three Tanks Completed and Ready for Installation of Piping. Note Concrete Wall Surrounding the Tanks

inch. Vertical braces are angles $1^1/_4$ inch by $1^1/_4$ inch by $^1/_4$ inch. The corner angles are 3 inch by 3 inch by $^3/_8$ inch.

In welding the trusses, the entire assembly was placed in a jig (see Fig. 10) to insure accurate spacing, alignment and squareness. The trusses were welded up in sections as shown and properly positioned on the tank bottom (see Fig. 11), which consists of steel plate $^3/_8$-inch thick welded together and resting on a concrete base. When the entire truss framing was properly placed, all trusses were tied together by angles extending completely across the framing at the intersection of each vertical and horizontal member, and welded to both verticals and horizontals.

When the entire frame had been tied together into one integral, the vertical members were welded to the steel bottom. Next step of construction consisted of attaching the $^3/_8$-inch side and end plating. Welding of the roof plating is shown in Fig. 12. Figure 13 shows the three tanks completed ready for installation of piping. Figure 13 also shows the concrete wall surrounding the tanks.

Bulk storage plants in metropolitan New York are adopting rectangular tanks increasingly. In congested districts, it is often possible to obtain greater storage capacity than would be possible with a cylindrical unit. In addition to providing greater capacity for a given space, the rectangular tank permits savings on concrete and reduces excavation. These savings make it possible to install rectangular units at considerably less cost.

The fast welding permitted by modern shielded arc equipment is to be noted in the short time required to build these large tanks. Exactly seven weeks after the first shipment of plate arrived on the building site, the last tank was tested and accepted. All welding was done with shielded arc equipment supplied by our Company.

Arc Welding Makes a (W)Ringer for the Scrubwoman

Arc welding, the obesity diet prescribed by so many metal products manufacturers today, has given the scrubwoman, that hard-worked member of the night shift, a new mop wringer, weighing only 12 pounds. The old type weighed $16^1/_2$ pounds. Naturally this reduction in dead weight has made a hit with Anne, Marie and the other girls.

The new model, fabricated entirely from smooth-lined steel stampings, is a neat-looking mop wringer and it is practically unbreakable. Moreover, improved features incorporated in the new design make it easier and safer to use. With advantages like these and its 30 per cent less weight, it is endowed with a mop wringer sales appeal all its own.

The manufacturers, Geer-Pres Wringer, Inc., Muskegon, Mich., report that the cost of the new fabricated design is considerably less than that of the old cast-iron design.

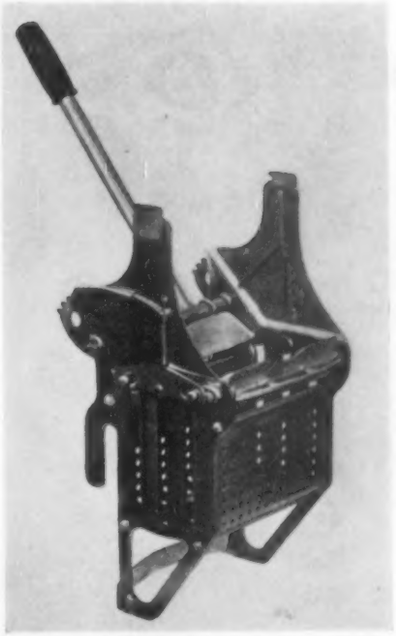


Fig. 14—This All-Steel, Arc-Welded Mop Wringer Weighs 4½ Pounds Less and Costs Less to Manufacture Than the Old Cast-Iron Model

1935 BOUND VOLUME

Bound Volumes of the JOURNAL of the Society for the year 1935 are now available with imitation black leather covers. Contains a wealth of information on the latest developments in welding. Also contains Subject and Authors' Index. Price, $5.00 plus postage to members; $6.50 to non-members.

The Welding of the Alloy Steels*

By J. C. HODGE†

WITH the almost limitless number of combinations of alloying elements which may be used in the alloying of steel, and with the present large number of various commercial alloy steels, any general discussion of the welding of such steels must be based on a method of classifying them. The classification may be made by a number of methods:

(1) Chemically, by designation of the alloying element or elements such as nickel steel, chromium steel, manganese-vanadium steel, chromium-manganese-silicon steel, etc. Each of these may in turn be further classified based on the amount of alloying element present; for example, 4 to 6% chromium, 12 to 14% chromium, 16 to 18% chromium, etc. The S. A. E. steel specifications represent an excellent example of this type of classification.

(2) By designation of the intended use, such as tool steel, machinery steel, automotive steel, corrosion resistant steel, structural steel, etc.

(3) Metallographically, by designation of the state of the carbide constituent in the alloy steel, i.e., pearlitic, sorbitic, martensitic, etc.

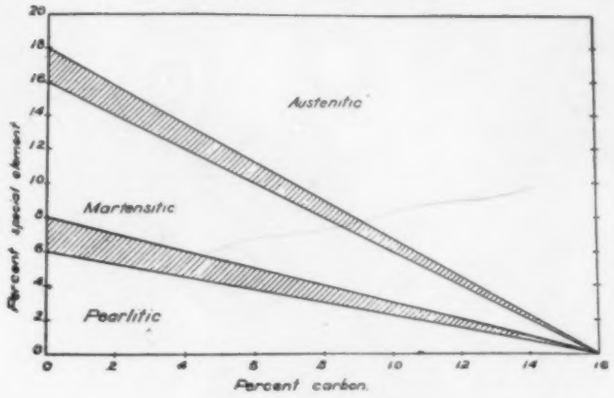
(4) By designation of the critical rate of cooling for hardening, such as water hardening, oil hardening, air hardening, etc.

All of the fusion welding processes involve the deposition of molten metal on or between the parts to be joined, the molten metal being rapidly cooled by reason of absorption of the heat of the relatively small amount of weld metal by the surrounding larger mass of colder parent or base metal. The welding processes also involve the heating of the parent metal to varying temperatures, producing a thermal gradient from the melting temperature at the line of fusion to the normal temperature of the parent metal at some distance from the joint. This thermal gradient will change depending on whether or not a preheating of the parts being welded has been re-

* Paper presented at the Fall Meeting of the AMERICAN WELDING SOCIETY, October 3, 1935.

† Babcock & Wilcox Company.

Fig. 1—Guillet's Constitutional Diagram for Alloy Steels (from Sauveur's "Metallography and Heat Treatment of Iron and Steel")



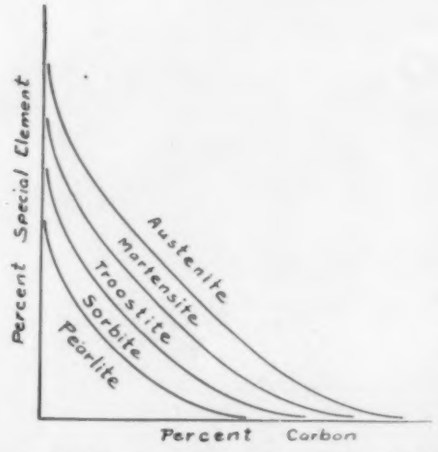


Fig. 2—Constitutional Diagram for Alloy Steels in General, Modified by Sauveur

a b c

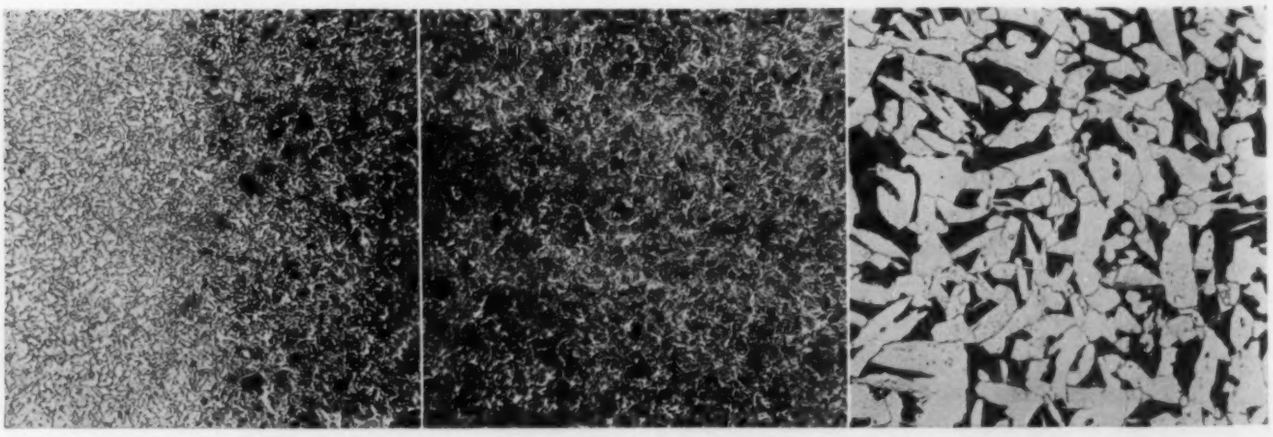


Fig. 3—(a) Fusion Zone, (b) Affected Zone and (c) Original Structure of a 0.25 to 0.30% Plain Carbon Steel. Note Sorbitic Structure in Affected Zone

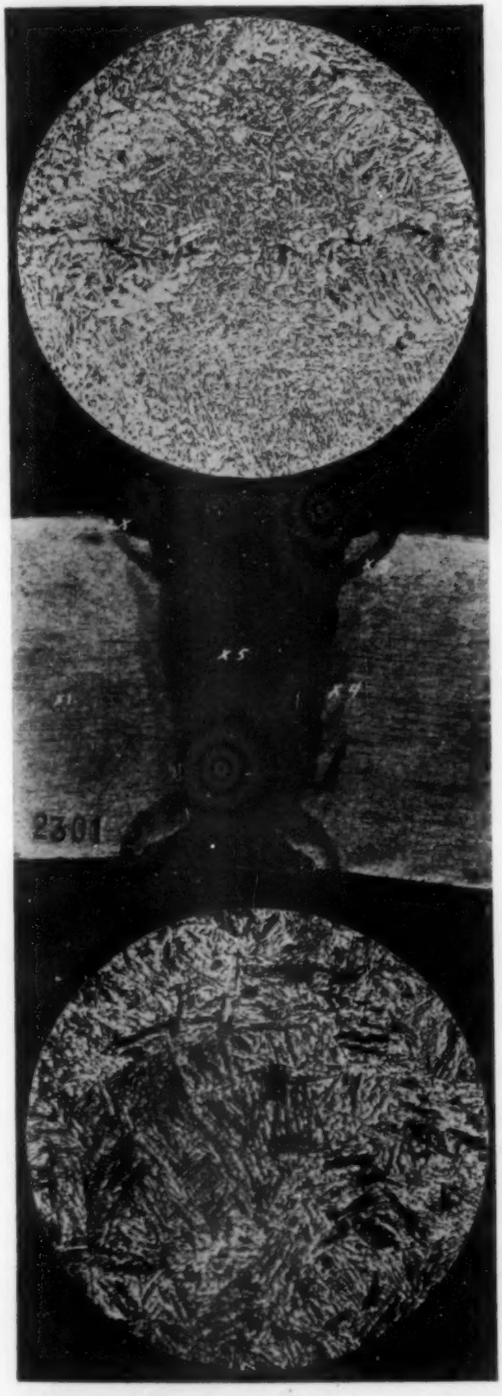


Fig. 4—Crack in Martensitic Weld Metal (3.5% Ni, 0.20% C) BHN 350

Fig. 5A—Macro - Structure of Welded Joint in 2-In. Thick Plate of SAE-3340 Analysis

Fig. 5B—Martensitic Structure of Affected Zone at Top of Joint (Fig. 5A) Adjacent to Last Weld Bead Deposited. BHN 450

sorted to, the preheating temperature, the thermal capacity of the parent metal and the heat input of the welding process used. In multiple bead or weld layer deposition where more than one pass of the welding element is required to fill in the joint, the weld metal and parent metal may be subjected to repeated heating and cooling. For these reasons a discussion of the welding of alloy steels must involve a discussion of the metallurgical changes resulting in heating them to various temperatures up to the melting point and in subsequently cooling at various rates from these temperatures.

These effects may be best described in a very general and elemental way by considering the alloy steels under the last two classifications presented earlier in the discussion.

General Metallurgical Considerations

Figure 1 shows Guillet's classical constitutional diagram for alloy steels in general. Arbitrary percentages of carbon and of the special element have been, of course, selected. The diagram does not cover all types of alloy steels but is sufficient for our general discussion. (For a more complete discussion any standard text-book such as Sauveur's "Metallography and Heat Treatment of Iron and Steel" may be referred to.) The diagram shows the structural constituent characterizing a steel of known alloy and carbon contents slowly cooled from a high temperature, and by it we may predict the general properties of any given steel, its general behavior on heat treatment, and in a somewhat indirect manner the general hardening propensity of the steel on cooling from welding temperatures.

For a given carbon content, increasing the alloy content causes the steel at normal temperature to exist in the pearlitic, martensitic and austenitic condition in succession.

For a given alloy content, increasing the carbon content results in conversion from pearlitic to martensitic to austenitic condition in succession at normal temperatures.

The commercial plain carbon steels considered weldable under usual welding technique, i.e., 0.35 or 0.40 maximum carbon and with alloying element approximating $^3/_4$ of 1% maximum, occupy an extremely small corner of the pearlitic zone of the diagram.

The commercial low alloy structural steels with carbon up to 0.35% maximum and special alloying elements up to 3.50%, also occupy a small corner of the pearlitic zone of the diagram.

The balance of the field covers special alloy steels, commercial austenitic steels being best represented by high nickel-chromium stainless steels as, for example, 18% chromium-8% nickel; or by Hadfield's manganese steel of 12% manganese and 1% carbon.

Strictly speaking, the diagonal lines between the various types of structure should not intersect the axes of the diagram but should be asymtotic to those axes as shown in Fig. 2. Additional zones showing the sorbitic and troostitic transition structures between martensite and pearlite have been introduced.

As previously stated, however, the two diagrams shown are for alloy steels after slow cooling from above the critical temperature. The effect of rapid cooling such as is encountered with normal welding technique is to depress the lines of demarcation of the various structural zones toward the lower left-hand corner of the diagram. This effect is further enhanced by the extremely high temperature from which the weld metal cools. The effect of $T^{max.}$ on the hardness of an alloy steel air cooled from successively higher temperatures may be illustrated by

Fig. 6—Welded Section of 30-Ft. Diameter Penstock, Plate Material 2"/8-In. Thick High Yield Strength (Modified Carbon Steel Analysis)

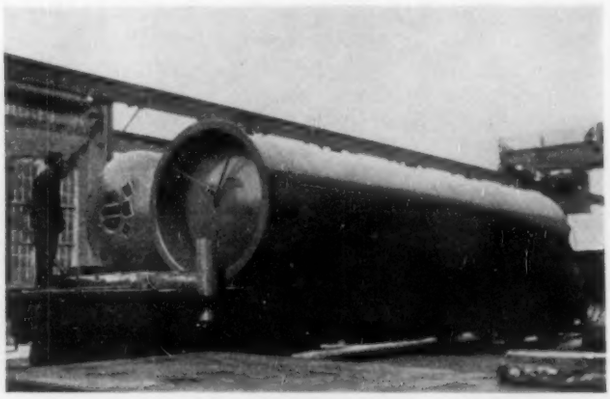


Fig. 7—Pressure Vessels of High Tensile Strength Plate (70,000 Lb./Sq. In. Minimum) of Modified Carbon Steel Analysis

the following data on 4 to 6% chromium-molybdenum steel:

Effect of $T^{max.}$ on Hardness of Air Cooled 4 to 6% Chromium-1/2% Molybdenum Steel

	Air Cooled from 1500° F.	Air Cooled from 1600° F.	Air Cooled from 1700° F.	Air Cooled from Welding Temperature
0.23% carbon	159 BHN	393 BHN	444 BHN	
0.12% "	143 "	350 "	363 "	Approx. 450 BHN
0.05% "	131 "	253 "	302 "	

By reason of the relatively fast cooling from a very high temperature, a pearlitic steel will on welding show a sorbitic structure or a martensitic structure in the weld metal or heat affected zone. Even a 0.25 to 0.30% plain carbon steel will be sorbitic in the affected zone (Fig. 3). A 3.50% nickel, 0.20% carbon steel normally considered pearlitic, i.e., on slow furnace cooling, will possess a martensitic weld metal hard and brittle and liable to crack unless preheating is resorted to (Fig. 4). Similarly a steel corresponding to S. A. E.-3330 in analysis (3.50% nickel, 1.50% chromium, 0.30% carbon) will in the heat affected zone possess Brinell values as high as 450. Figure 5*A* shows a macrosection of a weld on 2-in. thick plate of this alloy steel. The Brinell hardness value of the affected zone will vary depending upon the location, since this is a multiple bead weld and the lower portions of the affected zone have been subjected to repeated heating and cooling from subsequent welding, resulting in tempering of varying degree. For example, the hardness of the affected zone near the center of the plate thickness is 260 Brinell, while the hardness of the affected zone at the top of the joint (adjacent to last bead deposited) is 450. The hard martensitic structure of this topmost portion of the affected zone is shown in Fig. 5*B*. The hardness of the weld metal will, of course, vary with the analysis of the electrode used.

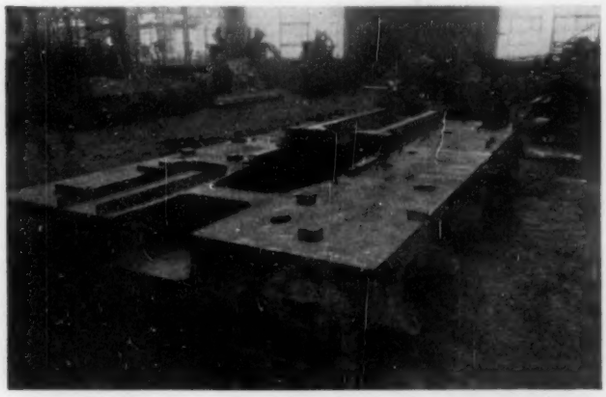


Fig. 8—Engine Bed Plate of High Speed Train. Bed Plate of Welded Cromansil Plate 1/4 to 3/8 In. Thick

The austenitic steels are characterized by great ductility and toughness, the martensitic and troostitic steels by hardness and brittleness and the sorbitic and pearlitic steels by a desirable combination of strength, toughness and ductility. The austenitic steels are therefore considered to be readily weldable since toughness permits resistance to welding stresses without fracture. Steels which remain pearlitic or sorbitic in the heat-affected zone, i.e., pearlitic steels which do not weld harden, may be readily welded. Steels which become martensitic in the heat-affected zone are weldable only with difficulty since their hardness does not permit deformation without fracture under welding stresses. Such steels require preheating for prevention of cracks and annealing immediately after welding to transform the hard structure to more ductile sorbite or pearlite. Theoretically, it is possible to fusion weld any martensitic alloy steel which can be cast and hot worked provided preheating is employed and corrective heat treatment subsequently applied to the welded structure. In practice, however, this procedure becomes impossible in many cases by reason of the magnitude of the structure to be welded.

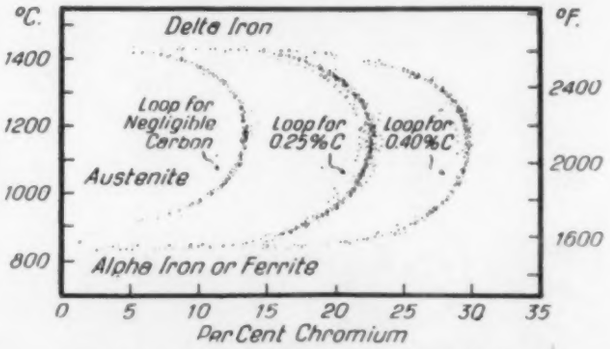


Fig. 9—Diagram, According to Bain, Showing the Effect of Increasing Carbon in Extending the Austenitic Loop in the Structural Diagram to Regions of Higher Chromium

The necessity for heat treatment after welding will vary depending upon the alloy steel being welded and the service to which the welded structure will be subjected. For low alloy structural steels where weld hardening is no greater than in mild plain carbon steel, rules governing the stress relieving of the plain carbon steel will suffice. When the air or weld hardening becomes more marked, the necessity for stress relieving becomes proportionately greater. For the higher alloy steels such as the chromium stainless steels and irons, heat treatment usually becomes mandatory, either to eliminate excessive weld hardening as in the 4 to 6% chromium steel or to eliminate a condition which might result in service failure by corrosion such as carbide precipitation in the heat affected zone of nickel-chromium austenites.

Low Alloy Structural Steels

The use of alloy structural steel, i.e., steel in the form of plates and structural shapes used in bridge building, freight car, ship building and pressure vessel construction, and for the frames and bed plates of machine tools and engines, has been limited in the past to a comparatively small tonnage. As contrasted with the relatively small parts entering into the construction of an automobile, large structural pieces such as bridge members or

finished fabricated units such as large pressure vessels cannot be subjected to a quenching and drawing operation to develop the optimum properties of alloy steel. In such large sections or structures increased strength and ductility is solely dependent upon the presence of the alloying elements without the more important benefit of heat treatment. The best that can be done is to use alloy structural steel in the normalized (air-cooled condition), resulting in tensile strengths of 65,000 to 100,000 lb. per square inch as compared with 125,000 to 150,000 lb. per square inch or higher tensile strength for heat treated alloy steel. Indeed, it is extremely doubtful whether the structural designer would use an extremely high tensile strength steel even if it could be made available by heat treatment, since there is obviously a limit to which he can go in lightening a structure, and the use of an extremely high strength alloy steel with its accompanying lower ductility and toughness is doubtful practice in the design of large structural members.

Without attempting to tabulate the chemical analyses of the various low alloy high tensile steels, the following enumeration of different commercial steels of this classification recently produced commercially is of interest: 2 to 3.5% nickel steel, 1 to 1.5% manganese steel, 0.20 to 1% silicon steel, copper bearing steel, carbon-molybdenum steel and the more complex steels such as chromium-manganese-silicon (Cromansil steel), chromium-silicon-phosphorus-copper (Cor-Ten steel), manganese-copper (Man-Ten steel), chromium-molybdenum or vanadium steel, manganese-vanadium or molybdenum steel and copper-molybdenum steel. The choice of any one of these alloy steels will depend entirely on the service conditions. All of them possess high yield point and high tensile strength even in the as-rolled condition without further heat treatment. The ratio of yield point to tensile strength is high by reason of the alloy additions.

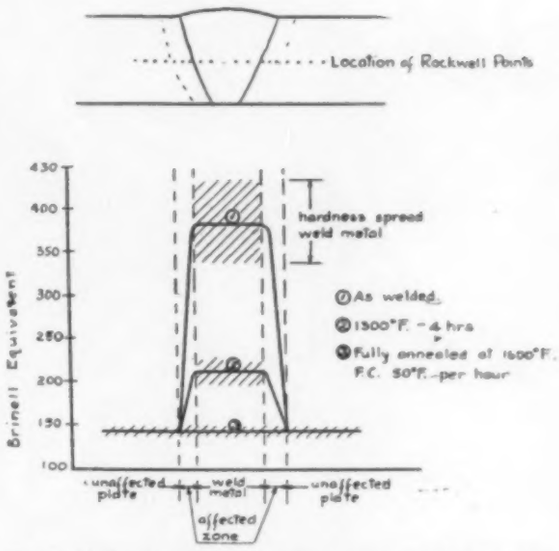


Fig. 11—Hardness across 4 to 6% Chromium-½% Molybdenum (1) as Welded, (2) Annealed 1300° F. 4 Hours, (3) Fully Annealed at 1600° F. Furnace Cooled at 50° F. Per Hour

Fig. 10—X-Ray Print of 4–6% Chromium-Molybdenum Welded Joint, Showing Numerous Transverse Cracks across Weld, Due to Lack of Preheating Prior to Welding

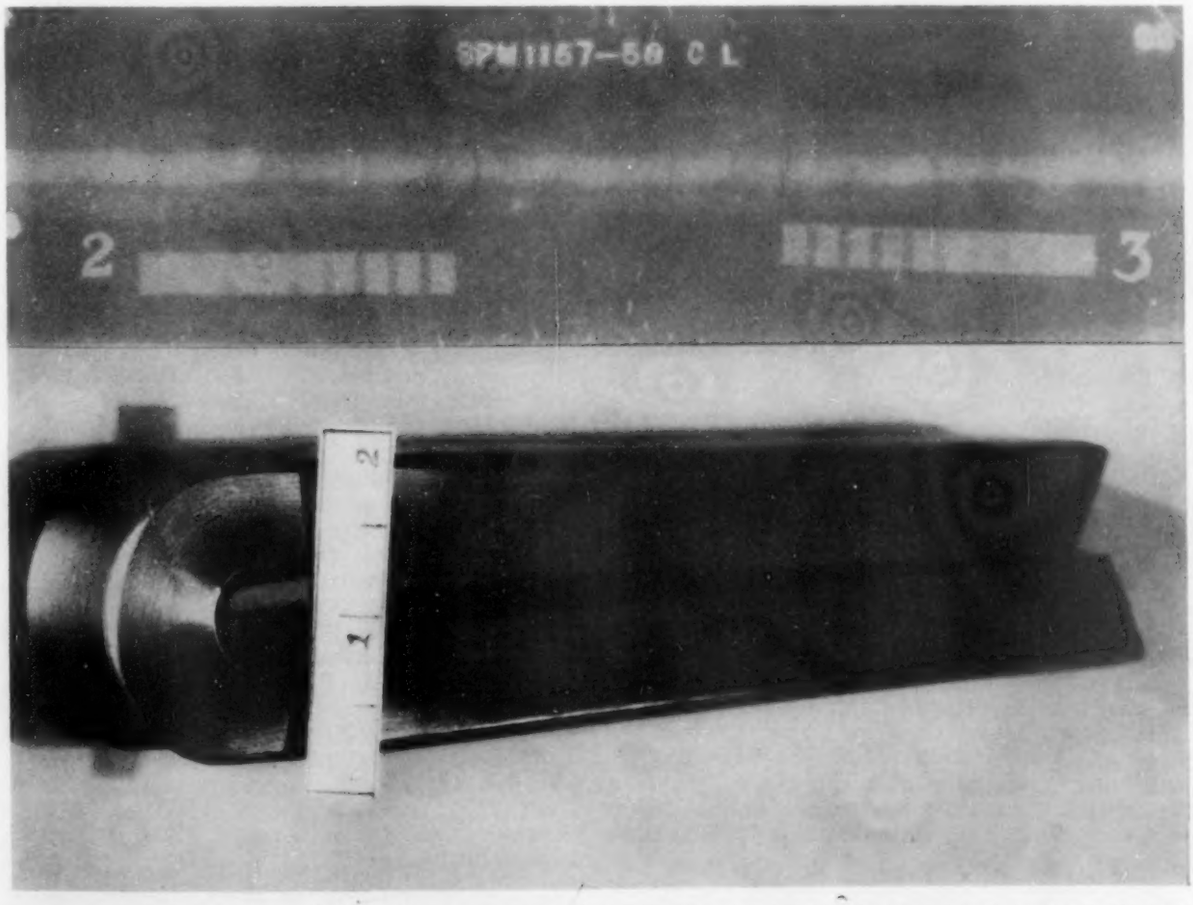


Fig. 12—Bend Test of ¾-In. Thick Weld Specimen 4–6% Chromium-Molybdenum. Elongation of Outer Fibers during Bending, 67%. (Weld Fully Annealed.) 4–6% Chromium-½% Molybdenum

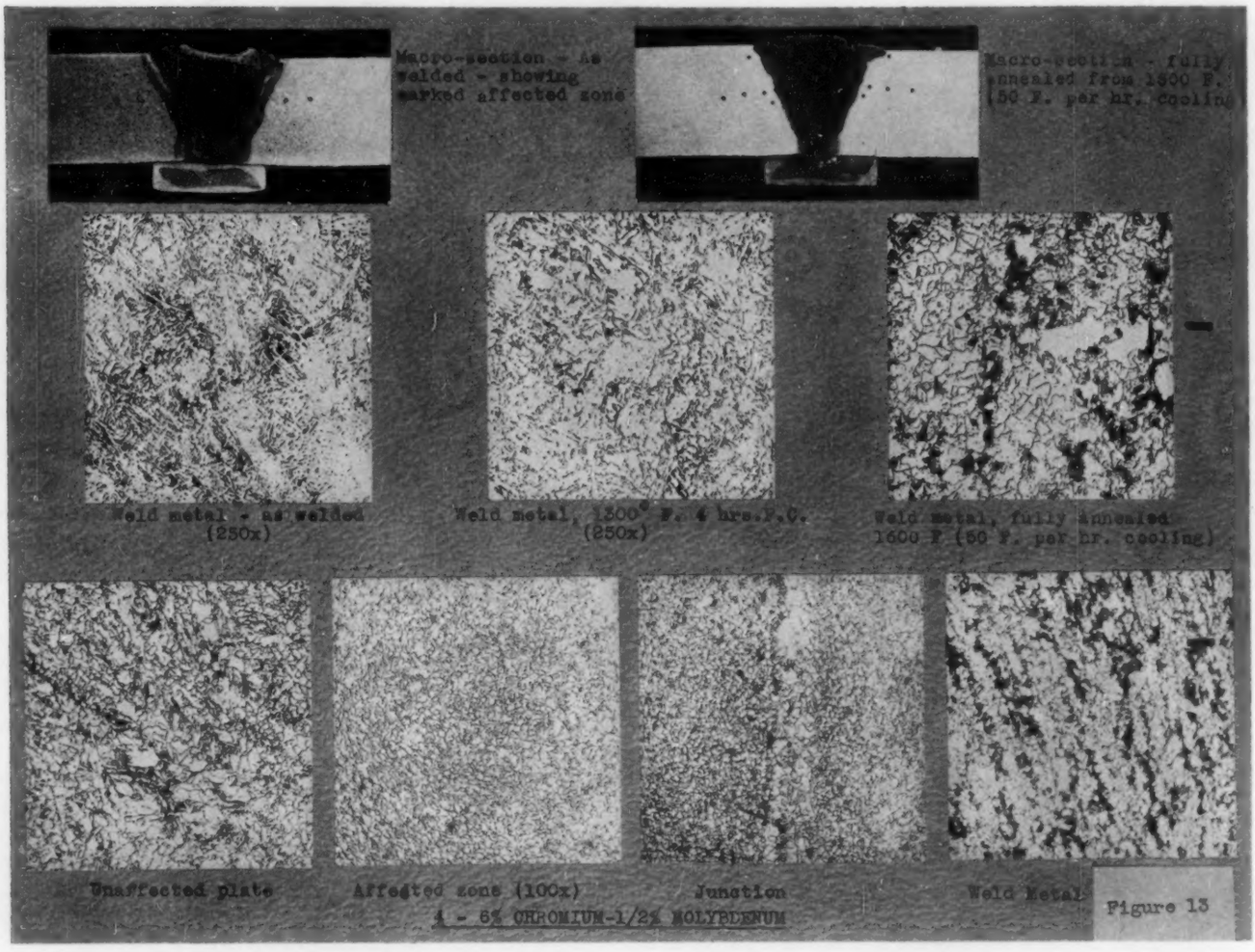

Macro-section - As welded - showing marked affected zone
Macro-section - fully annealed from 1600 F. (50 F. per hr. cooling)
Weld metal - as welded (250x)
Weld metal, 1300° F. 4 hrs.F.C. (250x)
Weld metal, fully annealed 1600 F (50 F. per hr. cooling)
Unaffected plate
Affected zone (100x)
Junction
Weld Metal
4 - 6% CHROMIUM-1/2% MOLYBDENUM

Figure 13

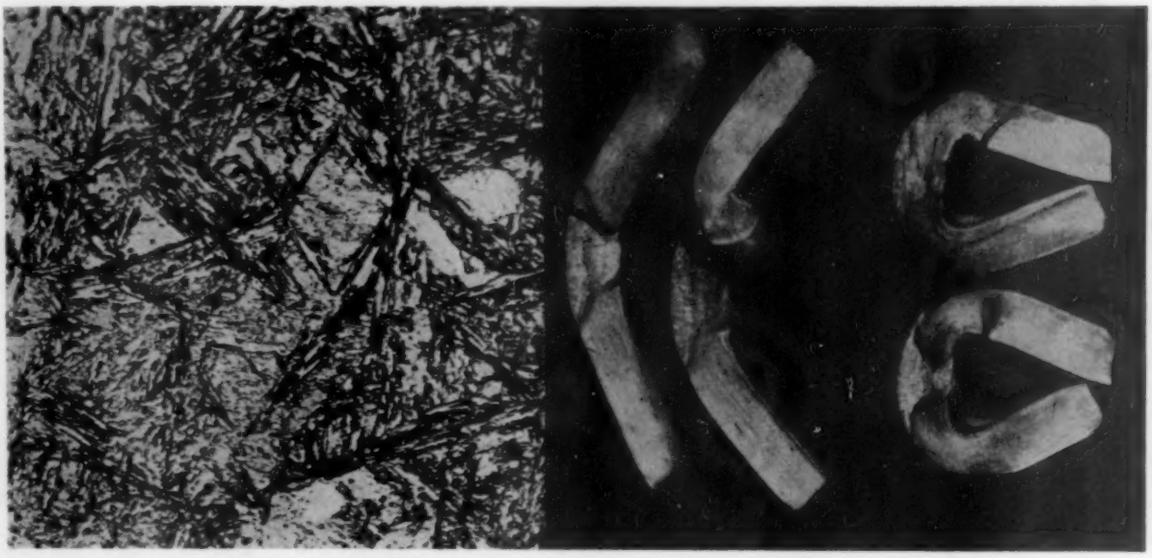
Some of them will possess added corrosion resistance since slight amounts of alloying elements, such as nickel, chromium, copper or molybdenum, confers upon the steel a surprisingly large increase in resistance to certain corrosive media such as atmosphere, impure boiler feedwater or mine waters. For high temperature service such as plates for pressure vessels at elevated temperatures, certain of the low alloy steels possess improved creep resistance, i.e., resistance to plastic yielding of the steel under stress. For low temperature service such as pressure vessels and parts in the oil refining dewaxing process in the manufacture of dry ice and in the liquefaction of gases, the improved impact resistance of certain of the alloy steels such as the 2% nickel steels is utilized.

Mention should also be made of slight modifications in the usual plain carbon steel analysis, high yield strength and high tensile strength having been obtained by a slight increase in the usual contents of carbon, manganese and silicon. In the as-rolled condition plain carbon structural steel possesses a variable yield point. A normalizing treatment results in increased and more uniform yield point. It has been possible by the use of the modified plain carbon steel analysis or by the use of a strengthening normalizing treatment to greatly extend the field of plain carbon steel into applications where some of the low alloy steels would otherwise have been used.

Possibly the most interesting example of the savings in weight accomplished by the use of a high yield strength steel of modified carbon steel analysis, lies in the steel plates entering into the construction of the Boulder Dam penstocks (Fig. 6). In these penstocks the design called for a ratio of yield strength to working stress of 2:1, which necessitated on the basis of 19,000 lb. per square inch working stress, the use of a steel with a minimum yield strength of 38,000 lb. per square inch. Ordinary plain carbon plate with much lower yield strength was, of course, permitted, provided the thickness was increased to compensate for the lower yield point. The decreased thickness resulting from the use of high yield strength steel plate also resulted in appreciable savings in the amount of welding required.

In the boiler and pressure vessel field the higher operating pressures and temperatures of the vessels, requiring heavy plate of the usual carbon analysis with attendant difficulties in fabricating heavy plate, brought a demand for a high tensile plate. This was met by two new specifications of the A. S. T. M., also adopted by the A. S. M. E. Boiler Code, covering high tensile plate, 70,000 lb. per square inch minimum, made of modified carbon analysis. In the past year a large number of pressure vessels have been fabricated of this plate material with a weight reduction of approximately 20 per cent (Fig. 7). While only one of the low alloy high tensile steels has been officially adopted for pressure vessel construction, and that for riveted construction only, welded vessels have been made of high strength chromium-vanadium steel and others for low temperature service of $2^1/_2$% nickel steel.

Numerous examples could be cited of weight savings in railroad cars resulting from the use of one or more high



a b c

Fig. 14—12–14% Chromium Iron. (a) Martensitic Structure of Weld Metal (13% Cr, 0.15%C). As-Welded Condition. Brinell, Weld Metal, 420–480. Brinell, Affected Zone 500. (b) As-Welded Specimen with Failure through Affected Zone. Brinell, Affected Zone 360. Brinell, Unaffected Plate 150–170. (c) Heat Treated Specimens (1450° F., F.C.). Failure in Base Metal. Brinell, Affected Zone 180–240. Brinell, Unaffected Plate 150–170. Bend Test Specimens of Low Carbon 13% Chromium Welds (C 0.07 Max.). Welded with 16% Chromium Electrode

tensile steels (Fig. 8). In one lot of cars the use of welding in conjunction with the high tensile steels resulted in weight savings of approximately 35 per cent, and undoubtedly large tonnages of low alloy high strength steels will be used for freight and passenger car construction where saving in weight is an important economic factor.

The majority of the low alloy high tensile steels previously enumerated have been developed for this purpose.

Practically all of these alloy steels may be successfully welded and used in the as-welded condition without further heat treatment, provided the sections are not too heavy to necessitate a stress relieving treatment, and provided the analysis is so balanced so as to minimize weld hardening of the alloy steels. This is accomplished by holding the carbon content to a minimum where the total alloy content is relatively high. For structural purposes and operating at normal temperature under static loads, the electrodes used may be of normal plain carbon steel chemistry, since the deposited weld metal in the as-welded condition or after stress relieving at the usual temperatures, possesses a high yield point of approximately the same value as that of the alloy structural steel. In general, however, electrodes are available which will deposit weld metal of the same approximate composition for each of the alloy steels.

The Stainless Steels and Irons

We may now consider briefly the welding of the second important group of steels which are welded in large commercial quantities—the stainless steels and irons. The quality of corrosion resistance or stainlessness is imparted by adding chromium to the steel in varying quantities. In general the higher the chromium content the greater the corrosion resistance of the alloyed steel. In order to appreciate the welding characteristics of these steels it is necessary to understand their metallurgy and, since the iron-chromium-carbon alloys depart considerably from the general behavior of alloy steels as predicated in our general constitutional diagram for alloy steels of Figs. 1 and 2, it is necessary to consider the constitutional diagram of the iron-chromium-carbon alloys as shown in Fig. 9.

This diagram, according to Bain, shows the stable structural conditions of any of the straight chromium irons throughout the temperature range. For a given carbon content the effect of increasing the chromium is to raise the alpha to gamma transformation temperature and to lower the delta to gamma, so that eventually a chromium content is reached at which the two transformation lines merge, forming what is termed the "gamma loop." Above this chromium content the irons or steels are transformationless, i.e., single phase alloys. Grain refinement by reason of recrystallization is therefore impossible. Heat treatment for change in grain structure and in physical properties is not possible, the only effect of high temperature treatment being an enlargement of the crystal or in grain growth. Below this chromium content, where the two transformation lines merge to form the austenitic loop, the chromium iron alloys are heat treatable and hardenable. The effect of carbon, manganese and nickel additions to the chromium irons is to enlarge the gamma loop in the manner as shown in the diagram for carbon. The effect of aluminum, silicon and titanium additions is to depress the gamma loop.

Welds in the lower chromium range will therefore be subject to air hardening but may be heat treated and varying physical properties obtained. Welds in the higher chromium series beyond the gamma loop will be non-hardenable but brittle. Between these two will lie a borderline group of alloys which are not subject to marked air hardening but which may be heat treated to confer some degree of toughness upon the weld. These alloys will lie immediately below the chromium content necessary for merging of the two transformation lines but where the lower critical point is sufficiently high to prevent excessive air hardening.

The following brief discussion of the welding of the various types of stainless steels and irons has been largely extracted from a more complete presentation of the subject by the author in Thum's "Book of Stainless Steels," second edition.

4 to 6% Chromium Steels

The 4 to 6% chromium steels, either with or without the usual tungsten or molybdenum additions, possess distinct air hardening tendencies, and as carbon enhances their air hardening propensities the lower carbon ranges of the alloy are generally chosen where welding is

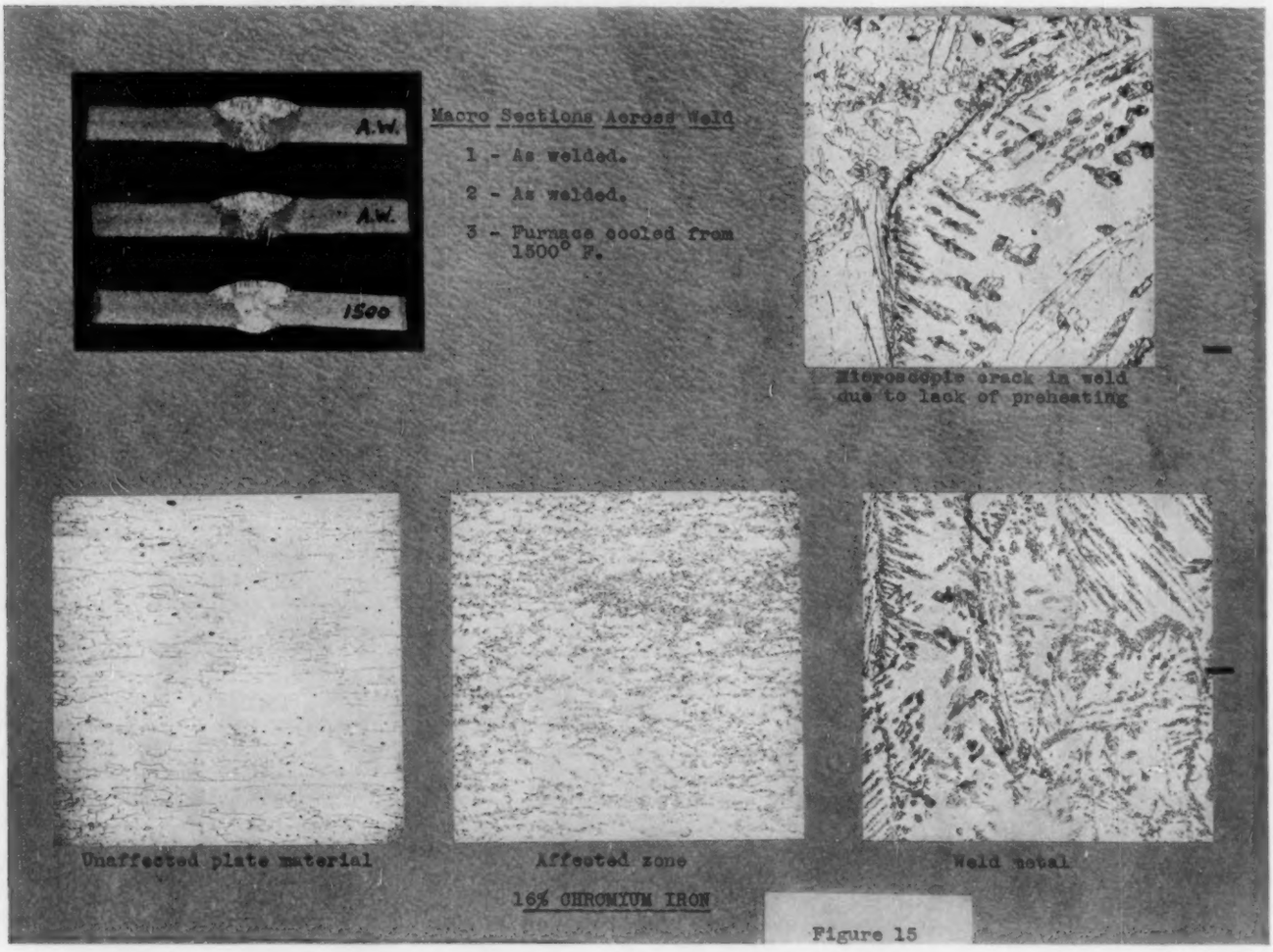


Figure 15

to be considered. Experimental data indicate that titanium or aluminum additions may be used to prevent or diminish excessive air hardening.

Welds from electrodes of the same analysis will crack unless preheating is resorted to (Fig. 10). Cracking of the weld metal may be prevented by preheating the parts to be welded, either locally or uniformly, to a temperature of 300 to 400° F., and maintaining that temperature until completion of the welding and placing in the annealing furnace.

Figure 11 shows the variation in hardness across a welded joint in the as-welded condition and after heat treatment. Maximum softness of the weld is attained by a full anneal at 1600° F., followed by slow furnace cooling at a rate of 50° F. per hour until a temperature of 1200 to 1300° F. is reached, at which the part may be removed from the furnace and air cooled. Satisfactory softness for most purposes may be achieved by a lower temperature anneal at 1300° F.

Metal arc welded joints are being produced to all requirements of the A. S. M. E. Boiler Code for class one welding. Figure 12 shows a bend test specimen from a large number of production welded test plates, where the specimen has been bent flat on itself with an accompanying elongation of the outer fibers of the weld metal of 67%.

Typical macro-structures and micro-structures are presented in Fig. 13.

12% Chromium Steel

The 12% chromium steel is generally considered to possess a chromium range of 11 to 14%, with low carbon up to 0.15% maximum. The cutlery steels may also be considered in this group, with higher carbon contents and sometimes higher chromium contents than the range given above. Even the low carbon type is a martensitic steel (Fig. 14) and, with its pronounced air hardening, may be considered as possessing only limited weldability. To successfully weld these steels requires preheating to a high temperature, with heat treatment following immediately after welding.

With extremely low carbon (carbon 0.07% maximum), the air hardening of the alloy is minimized and the use of welded structures of this low carbon steel in the as-welded condition may be considered (Fig. 14*B*).

Considerable quantities of a modified analysis possessing little or no air hardening characteristics, i.e., 13% chromium-$^1/_4$% aluminum, are being used commercially for welded structures in the as-welded condition.

16% Chromium Irons

Alloys with chromium from 15 to approximately 18% and with carbon contents of below 0.15% represent a transition zone from the pearlitic or martensitic alloys below this chromium range to the fully ferritic alloys above this range. They are susceptible to heat treatment and at the same time do not air harden appreciably.

While it is possible to metal arc weld this group at normal temperature, preheating, at least locally, to approximately 200° F. is advisable. In the as-welded condition the welded joints are extremely brittle and, where highly stressed in service or subject to possible impact, should be annealed at 1450° F.

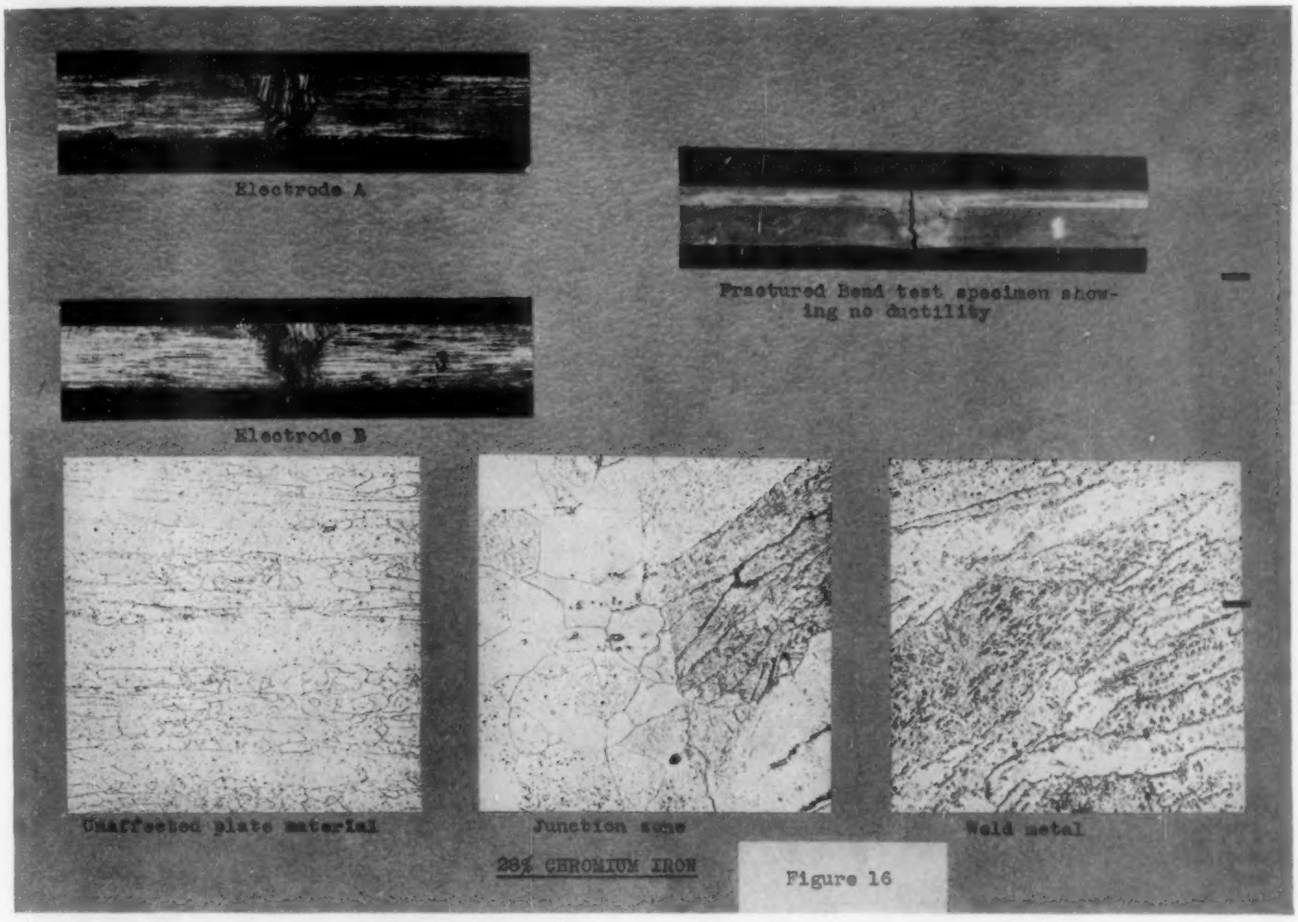


Figure 16

In the annealed condition the welded joints possess satisfactory ductility and impact resistance. The toughness of the weld will depend largely on its chromium content, the impact resistance of the weld metal dropping sharply at chromium contents of above approximately 17.25%.

Typical macro- and micro-structures are shown in Fig. 15.

Chromium Irons Above 18%

Chromium iron alloys above 18% and with normal carbon contents are entirely ferritic. These single phase alloys are not responsive to heat treatment, do not air harden and are subject to grain growth at elevated temperatures. The weld metal and the affected zone of the base metal are therefore extremely coarse grained and brittle. The welds cannot be toughened by heat treatment and the alloys in this range may be considered as possessing extremely limited weldability. The more important chromium alloys of this group lie within a range of 26 to 30% chromium.

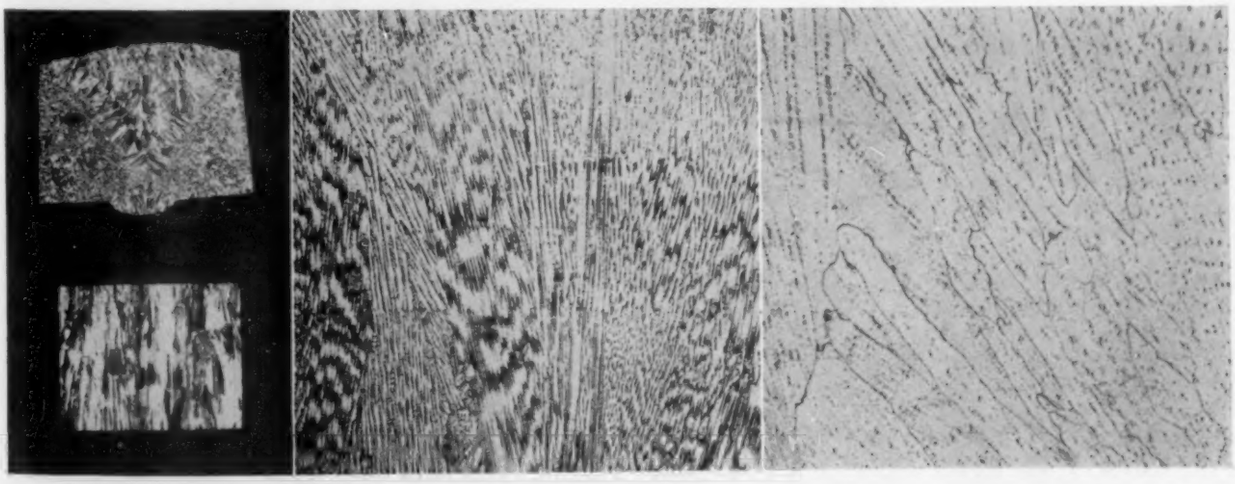


Fig. 17—Austenitic Nickel-Chromium Alloys

Macro-sections, transverse to weld, and longitudinal along weld, showing dendritic structure of these weld metals

35X
Dendritic structure of austenitic weld metals

100X
Large grains of austenitic weld metals

In welding these high chromium irons, preheating is again necessary, and residual welding stresses should be removed by an annealing treatment. Figure 16 shows typical macro-structures and micro-structures of a metal arc weld on 28% chromium iron. The macro-section captioned "Electrode A" represents a weld made with electrodes of normal 28% chromium iron analysis, while the section captioned "Electrode B" was made with an electrode of high nitrogen content, the high nitrogen in the weld metal apparently assisting to some extent in controlling the grain size of the weld metal in the same manner as has been reported for castings of this analysis.

Austenitic Chromium-Nickel Alloy Steels

This group comprises a large number of chromium-nickel alloy steels with varying chromium and nickel contents, such as 18-8, 19-9, 20-10, 23-11, 25-20, etc. Alloy modifications of several of these exist such as 18-8 with 2½% silicon or 3% molybdenum. Other alloy additions may be employed such as titanium or columbium for stabilizing purposes. All of these austenitic alloys may be readily welded. The effect of welding on the parent metal will vary considerably for each alloy, and the necessity for heat treatment and the response of the affected zone and the weld metal to heat treatment must be individually considered.

All of the austenitic welds of this group possess a marked dendritic structure as shown in Fig. 17. The weld metal is tough and ductile however.

The foregoing discussion has been necessarily limited as to details. It was impossible to cover in detail the welding of each individual alloy steel. It is hoped, however, that the article will convey the basic metallurgical principles governing the welding of alloy steels.

Welding and Cutting High Chromium Steels*

By W. J. PRIESTLEY†

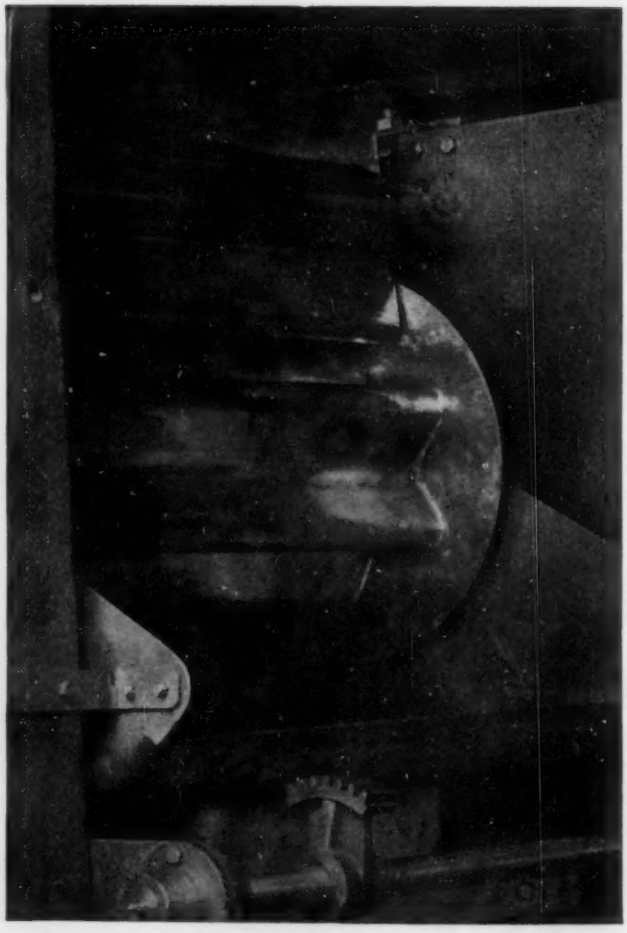
Improved Methods Based on Properties of Chromium Alloys

IN the fabrication of equipment by welding greater tonnages of alloy steel are being used to replace carbon steel for service that calls for lighter weight construction, and for resistance to wear, corrosion and oxidation at high temperatures. For most of these services chromium is the essential element and it is used in varying amounts in the steel from 0.5 per cent up to 30 per cent.

When it first became necessary to weld equipment of the high chromium and stainless steels, it was at once evident that there were problems that would have to be solved before entirely satisfactory performance could be assured. The reaction of chromium to the welding flame, the removal of infusible oxides, the effect of carbon pick-up, and most important, the metallography of the weld metal and heated areas, were factors that had no exact counterparts in welding mild steel. These new factors profoundly influenced the development of correct welding procedures and the choice of materials. The successful fabrication of these high chromium steels has been accomplished by the combined efforts of chemists, metallurgists and engineers.

Effect of Chromium on Welding Properties

The presence of large amounts of chromium in the steel necessitated several changes in welding methods that were entirely predictable from the knowledge of the nature of the metal, chromium. Chromium, at high temperatures, has a marked affinity for both oxygen and carbon. Translating this to the welding of high chromium steels, it is evident that flame control is exceedingly important. An oxidizing flame would remove chromium from the metal as chromium oxide and produce unsound, brittle welds. Uses of an excess acetylene or reducing flame would promote the formation of chromium carbides which also would remove valuable chromium from the metal. The most satisfactory flame ad-



These Stainless Steel Corrugated Rolls for Crushing Citrus Fruits Are Fabricated by Oxyacetylene Welding

* Read before the 36th Annual Convention, International Acetylene Association, Cleveland, November 12, 13, 14 and 15, 1935.

† Vice-President, Electro Metallurgical Company.

Table 1*—Effect of Columbium and Titanium on Mechanical Properties of 4 to 7 Per Cent Chromium Steels

Cr	C	Cb	Ti	Yield Strength, Lb. per Sq. In.	Maximum Strength, Lb. per Sq. In.	Elongation in 2 In., Per Cent	Reduction of Area, Per Cent	Izod Impact, Ft.-Lb.	Brinell Hardness
5.44	0.10			149,500	181,000	5	12	22	375
5.41	0.11		0.75	84,000	100,000	18	68	24	163
5.62	0.09	1.04		98,000	111,000	16	62	59	192

* Data taken from "Titanium and Columbium in High Chromium Steels," Becket and Franks, T. P. No. 506, A. I. M. M. E. All samples in the as-rolled condition.

justment is therefore the neutral one with no excess of either oxygen or acetylene.

Not only is chromium metal easily oxidized when molten, but the oxide is very infusible, with the result that when formed during welding, it will act as an insulating blanket between the flame and the work and care must be taken to keep the amount formed as small as possible. The use of a flux with a high solvent power for chromium oxide is essential. Careful flame control plus minimum puddling and with no excess heating will keep the amount of oxide low, and by using a specially designed flux the objection to chromium oxide formation may be practically eliminated.

The metallographic changes in the weld metal and adjacent zones have presented difficulties that necessitated more than simple adjustment in welding technique and in the solution of these problems, metallurgists and chemists have played important rôles.

A broad, very general, classification of the high-chromium and stainless steels may be made as follows:

1. Steels containing from 4 to 7 per cent chromium, with or without additional elements, as molybdenum or tungsten.
2. Steels containing from 12 to 30 per cent chromium.
3. Steels containing from 18 to 30 per cent chromium and from 8 to 12 per cent nickel.

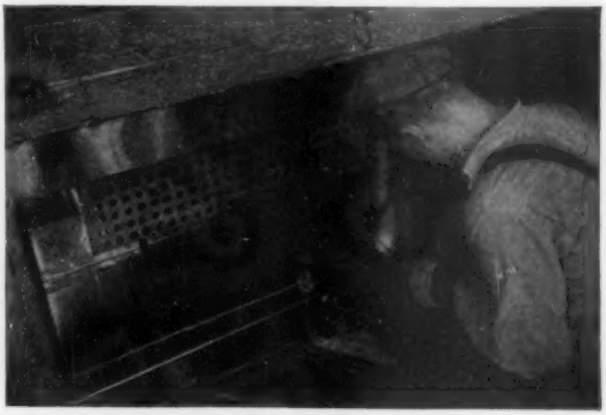
Steels Containing 4 to 7 Per Cent Chromium

Early experience with welding the 4 to 7 per cent chromium steels indicated that these steels were air-hardening, with the result that the weld metal and particularly the zone adjacent to the weld became hardened. The air-hardening was often accompanied by brittleness which complicated the welding, sometimes requiring expensive preheating or annealing procedures to prevent failure during and after welding. Since the air-hardening property of these steels was known to be due to the presence of chromium carbide, an extensive investigation was made to find other elements, with a marked affinity for carbon, which would "lock up" that troublesome element in the form that would make it unharmful. The two semi-rare elements columbium and titanium were found particularly effective for this purpose.

The addition of columbium or titanium to the 4 to 7 per cent chromium steels prevents air-hardening, and greater ductility is obtained, even in the as-rolled condition. The effect of these elements on the mechanical properties of this type of steel is shown in Table 1.

Because of the elimination of air-hardening, it is natural to expect that titanium and columbium will improve the welding properites of 4 to 7 per cent chromium steels. The results of an extended research program in welding practice indicate that these steels may be satisfactorily welded with a rod containing columbium and 6 to 8 per cent chromium.

The presence of either columbium or titanium also reduces the annealing time to minutes instead of the hours



The Technique for Using the 18-8 Columbium-Treated Stainless Steel Rod in the Fabrication of This Refrigerator Is Similar to That Required for Welding Ordinary Stainless Steel

often required for steels not bearing these elements. Because of this effect, marked improvement in ductility can be obtained in the weld by a simple blowpipe anneal. This consists of heating the weld with the blowpipe to a red temperature (1475 to 1650° F.) for one or two minutes. The softening range varies from 1300 to 1650° F. so the annealing can be performed without difficulty. Typical results of such anneals are given in Table 2.

Cutting 4 to 7 Per Cent Chromium Steels

Foundrymen, making castings of 4 to 7 per cent chromium steel, are sometimes confronted with a problem if they remove gates and risers from these castings by oxy-acetylene cutting. To prevent air-hardening and subsequent cracking, the usual procedure is to preheat the

Table 2—Tensile and Bend Tests on Blowpipe Annealed Oxyacetylene Welds in 4 to 6 Per Cent Chromium Steel Plate*

Condition of Sample	Yield Strength, Lb. per Sq. In.	Maximum Strength, Lb. per Sq. In.	Elongation in 2 In., Per Cent	Free Bend Angle
As Welded	30,000–40,000	55,000–65,000	4– 8	45– 90°
Blowpipe Annealed	30,000–40,000	55,000–65,000	8–12	120–180°

* Composition of plate: 5.51% Cr; 0.07% C; 0.56% Mo; 0.37% Ti. Welds were made in 1/4 in. annealed plate. Composition of welding rod was 6–8% chromium with columbium.

entire casting to a black heat (about 900° F.), at which temperature the steel is quite ductile. If the temperature of preheat becomes too high the entire casting may air-harden. In other instances, the risers are sometimes cut from dead annealed castings. This, however, may develop hard spots in the vicinity of the cutting, and the casting must be re-annealed to insure uniform softness.

Columbium or titanium in the 4 to 7 per cent chromium steels is effective in overcoming most of the difficulties of air-hardening, resulting from cutting these steels with the oxyacetylene flame. The use of titanium, however, may introduce certain casting difficulties which it is believed can be eliminated by the use of columbium.

Steels Containing 12 to 30 Per Cent Chromium

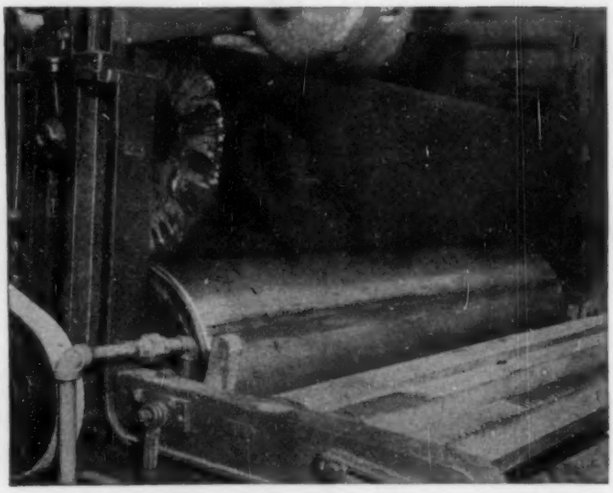
Results obtained from welding 4 to 7 per cent chromium steel with columbium-bearing welding rod led to experiments on the higher chromium steels, containing from 12 to 30 per cent chromium, since those containing less than about 14 per cent chromium also have air-hardening tendencies. The presence of columbium or titanium in these steels reduces this tendency, makes them more amenable to hot working and forming operations, improves their physical properties after welding and therefore widens their field of application. The effect of titanium and columbium on the properties of the plain chromium steels is shown in Table 3.

These Beaming Rolls, of 22-Gage 18-8 Stainless Steel Are Fabricated with Columbium-Treated Rod. They Are Used during the Washing of Woolen Cloth Preparatory to Dyeing

The higher chromium steels of low carbon content are subject to a coarse grain structure. This is especially true of ingots and castings which are cast at excessively high temperatures or held at a high temperature for a long time. The condition may be corrected by the presence of high nitrogen in the steel, which refines the grain, and makes the steel more ductile, even after welding.

Steels Containing from 18 to 30 Per Cent Chromium and 8 to 12 Per Cent Nickel

The welding problem encountered in the chromium-nickel austenitic steels, of which the 18 per cent chromium, 8 per cent nickel may be taken as most typical, is likewise due to the harmful effect of carbon, but in this case it is not that of air-hardening. The carbon in these steels acts to destroy their corrosion resistance by the formation of carbides along the grain boundaries and this promotes susceptibility to a type of corrosion commonly known as intergranular corrosion. These carbides form when the steel is held for a time within a certain temperature range. The chromium-nickel steels, as purchased, have been heated above this range and quenched, and have a homogeneous, corrosion-resistant structure. However, when they are reheated to a temperature within the approximate range of 500 to 1400° F., a new constituent forms along grain boundaries. The formation of this constituent lowers the corrosion resistance of the metal at these points and opens the way for between-the-grain attack by corrosive media.



The Bottom Beaming Roll of Stainless Steel, Unlike the Wooden One Above, Will Not Crack on Drying

During welding, the weld metal is heated to above the critical temperature and then cooled. There is insufficient time for precipitation of large quantities of the new constituent in the weld metal. However, the base metal in small zones close to and parallel to the weld remains heated within the critical range for a sufficient length of time and cools at a rate slow enough so that carbide precipitation takes place and these zones are subject to intergranular corrosion.

The weld metal itself, while relatively free from corrosion susceptibility, due to the welding heat, often suffers a decrease in corrosion resistance due to carbon pick-up from the welding flame.

Presumably anything that would lock up the carbon in these steels would improve their properties, and today a considerable tonnage of stainless steel, especially that designed for severe operating conditions, contains one or

Table 3*—Effect of Columbium and Titanium on Mechanical Properties of High Chromium Steels

Cr	C	Cb	Ti	Yield Strength, Lb. per Sq. In.	Maximum Strength, Lb. per Sq. In.	Elongation in 2 In., Per Cent	Reduction of Area, Per Cent	Izod Impact, Ft.-Lb.	Brinell Hardness
13.60	0.13			149,000	204,000	3	8	30	418
13.35	0.11		0.85	36,000	63,400	25	70	10	126
12.42	0.10	1.18		39,200	63,300	30	53	15	121
18.29	0.07			57,000	92,500	7	14	..	170
18.65	0.13		0.78	49,000	71,500	31	69	..	131
19.20	0.07	1.00		52,000	72,000	22	41	..	149
26.28	0.14			62,000	89,000	9	11	..	187
26.90	0.18		1.20	66,000	86,500	29	64	..	163

* Becket and Franks (see footnote Table 1). All samples in as-rolled condition.

Table 4—Tensile and Bend Tests on Oxyacetylene Welds in 1/4-In. Annealed Plate of 18 Per Cent Chromium, 8 Per Cent Nickel Steel

Cr	Ni	C	Cb	Ti	Yield Strength, Lb. per Sq. In.	Maximum Strength, Lb. per Sq. In.	Elongation in 2 In., Per Cent	Free Bend Test
18.22*	8.91	0.07			39,200	76,500	22	180° No Cracks
18.75**	9.02	0.10	0.98		37,200	75,400	20	180° No Cracks
17.42**	8.88	0.07		0.47	41,000	75,500	17	180° No Cracks

* Welding rod same analysis as plate.
** Welding rod analysis—18.34 per cent Cr; 9.01 per cent Ni; 0.07 per cent C; 0.81 per cent Cb.
All samples tested in as-welded condition.

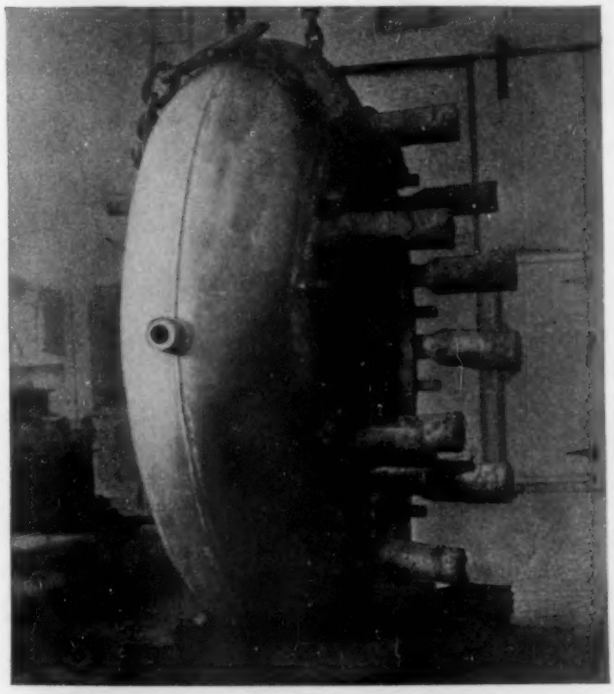
the other of the elements, columbium or titanium. They serve as a stabilizer for the carbon in the steel and prevent the structural changes that otherwise take place when the steel is held for a time in the temperature range between 500 to 1400° F. The harmful effect of welding heat on the zones adjacent to the weld is therefore eliminated. This means that heat-treatment after welding is unnecessary to secure full corrosion resistance.

Advantages of Columbium-Bearing Welding Rod

Since columbium is not lost from the weld metal during the welding operation, it is more satisfactory to use a welding rod containing columbium instead of titanium, regardless of what stabilizing element is used in the base metal. The presence of columbium does not complicate welding with the oxyacetylene flame and the free-flowing characteristic of the columbium-treated 18-8 rods makes them ideally suited for this practice. Columbium is especially beneficial since it counteracts the 0.02 to 0.04 per cent carbon which is picked up during welding. Oxyacetylene welds made on columbium-bearing plate using columbium-bearing rod have good strength and ductility. Table 4 gives an idea of the physical properties obtainable in oxyacetylene welds using columbium-bearing rod with columbium and titanium-bearing plate.

The amount of columbium necessary in the steel varies from 6 to 10 times the carbon content of the steel, depending upon the use for which it is intended.

The presence of columbium in the welding rod necessitates no changes in the welding procedure from that used on ordinary 18-8 stainless steel. The principle of a neutral flame and sufficient flux should be strictly followed. With columbium-treated plate and rod, backhand welding can be utilized to avoid the distortion that other methods of welding sometimes produce. With this technique, the weld metal and adjacent zones are held at a dull red temperature longer than by the usual forehand method. This need not be considered when columbium-bearing plates and rods are used, since the welding zone is amply protected.



A High Degree of Preheat and a Sawlike Motion of the Blowpipe Was Used in Cutting the Risers from This 18-8 Centrifugal Pump Casting. This Is One of the Largest Ever Cast

Oxyacetylene Cutting of High Chromium Steels

While it may seem incongruous to speak of using oxygen for cutting oxidation-resistant steel, this can be done quite satisfactorily. An accepted method of oxyacetylene cutting of chromium-nickel steel is that developed for riser cutting. An injector type cutting blowpipe is used with extra heat and a slightly carbonizing flame.

Stainless steel plate is often cut by the flux method, which consists in clamping soft steel plates on either side of the work to provide enough iron oxide and molten iron to flux away the more infusible chromium and nickel oxides. This may be accomplished also, by holding an iron rod in the cut to provide fluxing material.

Naturally these methods take more heat than is used in cutting ordinary steel and the heating effect on the stainless steel is apt to render it susceptible to intergranular corrosion, unless the steel contains a stabilizing element. Columbium and titanium counteract the harmful heat effects and eliminate the need of heat-treatment after the cutting operations have been performed.

Yoloy—Its Properties and Welding

By FRED J. ESSLINGER†

YOLOY is a word coined by The Youngstown Sheet & Tube Company, and represents their latest development along the lines of high tensile low alloy steels.

Yoloy, in addition to normal amounts of such elements as carbon, manganese, sulphur and silicon, contains moderate percentages of phosphorus, copper and nickel. The combined effect of the latter three elements imparts to Yoloy properties not revealed heretofore by any plain carbon or low alloy steels. It has a yield point almost double that of mild carbon steel, a very high tensile strength coupled with satisfactory ductility, a good degree of soil and atmospheric corrosion resistance, and excellent fatigue and impact characteristics; where it excels all other grades of ferrous alloys, however, is in its ability not only to retain its strength when heated and cooled from temperatures around 1000–1200° F., but actually to increase it. This feature alone makes the material particularly suitable for building of welded pressure vessels, boilers and similar subjects, since, unlike mild and medium carbon steel, it does not lose any of its strength when heated to high temperatures in the course of working and welding, nor falls short of the expectations of code requirements.

† Metallurgical Engineer, The Champion Rivet Company.

While the presence of phosphorus, nickel and copper in the alloy affects its physical properties so markedly, it does not affect its weldability in the least, and, if this operation is carried out with the proper type of electrodes, it yields joints every bit as good as the parent metal. The electrodes should be made of Yoloy wire of approximately the same composition as the material to be welded, and coated with a flux which will prevent any oxidation of the particles of molten metal passing through the arc and also assure their deposition in the weld in a form not differing chemically from that of the parent metal.

With the right kind of electrodes, the welding of Yoloy does not offer any more difficulties than the welding of mild carbon steel. The higher carbon types of the alloy should be preheated to 200–300° F., prior to their being welded, then tacked and the bottom layer welded with mild carbon electrodes. This mild carbon deposit can either be chipped out or left alone, since its presence will not materially affect the properties of the resultant joint. If possible, the welding should be done in the horizontal position and carried out with electrodes $^1/_4$ in. in diameter or preferably smaller. Reversed polarity

Fig. 1—Macrograph of Low Carbon "Yoloy" Weld

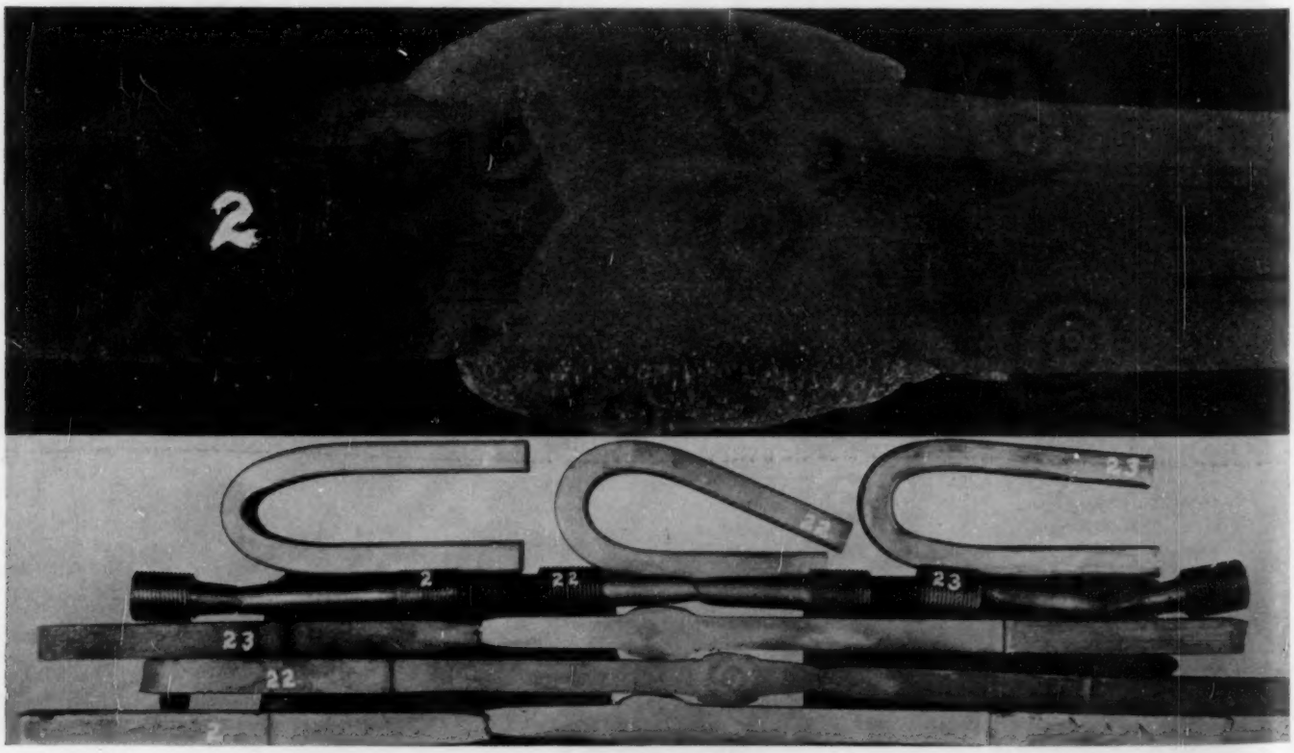


Fig. 2—Some Test Specimens

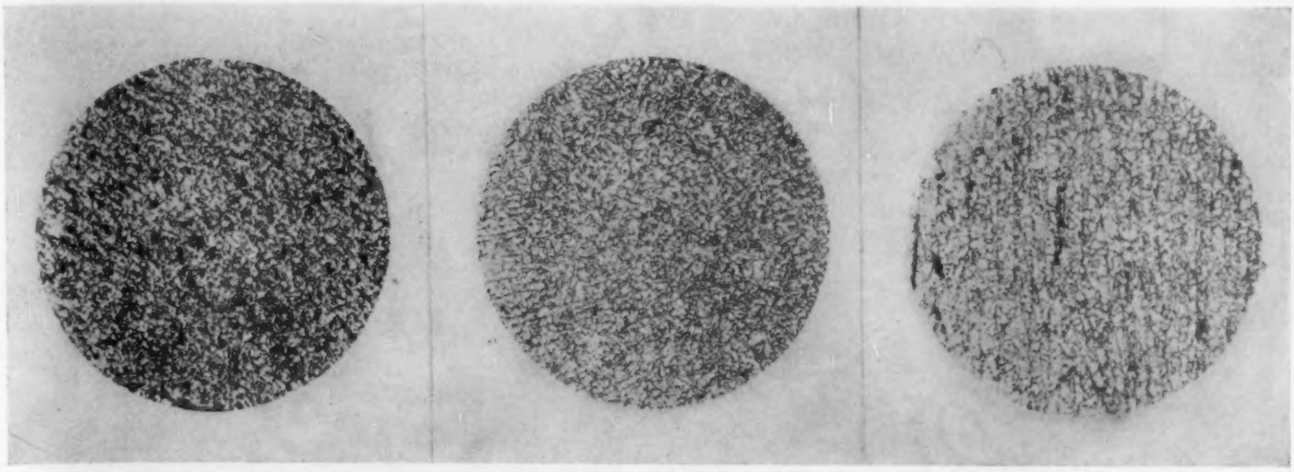


Fig. 3—Micro of Deposit in as-Welded Condition X 100

Fig. 4—Micro of Deposit after Heated to 1200° F. Followed by Slow Cooling X 100

Fig. 5—Micro of Deposit after Heated to 1580° F. Followed by Slow Cooling

direct current of the following densities ought not to be exceeded:

1/8 in. 80 to 100 amp.	3/16 in. 150 to 200
5/32 in. 100 to 150 amp.	1/4 in. 200 to 250

To prevent undue oxidation and excessive splatter losses, the voltage and, therefore, the length of the arc held in the course of welding should be at a minimum. The electrodes should be weaved in a crescent-like motion, and used to deposit layers not more than 1/8 in. in thickness and of the full width of the groove. The latter may be of the single or double U type, depending upon the thickness of the material to be welded and should not be excessively narrow at the top. Peening of the metal in between layers, while helpful in reducing stresses and warping, is not strictly necessary. Strain relieving of the work upon completion will be found almost indispensable. It is best carried out by placing the work in the furnace, raising its temperature gradually to 1200° F., holding it there 1.5 hours for every inch of thickness, and allowing it to cool back to normal within the furnace. This treatment effectively eliminates and equalizes all stresses set up in the work in the course of construction and at the same time increases its ductility without lowering its tensile strength, as would be the case with other materials.

Yoloy will upon short acquaintance prove a material decidedly less tricky to weld then many low alloy steels now on the market, and will, even in the hands of relatively inexperienced welders, yield results similar to those obtained by the author in his first attempt to weld this type of material. In this test 0.5-in. thick plates of low and medium carbon Yoloy were provided with 60 degrees single U grooves and welded with 5/32-in. and 3/16-in. electrodes, made from wire of the same composition as the plates. The welding procedure was the same as would have been applied in welding of mild carbon plates.

The completed samples were cut in strips, machined and tested in the welded, strain-relieved and annealed conditions, respectively. The results of the tests were as follows:

Full Size Tension Specimens

Condition of Material	0.08% C Plates and Wire Yld. Pt.	Tens. Str.	Fracture	0.20% C Plates and Wire Yld. Pt.	Tens. Str.	Fracture
As welded	58000	70000	2.0 in. from weld	66000	91000	2.0 in. from weld
Strain relieved	62000	73000	1.5 in. from weld	69000	92000	2.0 in. from weld
Annealed	63000	74000	2.0 in. from weld	68000	90000	1.0 in. from weld

The above results reveal clearly the tendency of the alloy, particularly the 0.08% carbon variety, to increase its yield point as well as tensile strength when heated to temperatures of around 1200° F. and then cooled.

All-Welded Metal Tension Specimens

Condition of Material	0.08% C Plates and Wire Yld. Pt.	Tens. Str.	Elong.	Red.	0.20% C Plates and Wire Yld. Pt.	Tens. Str.	Elong.	Red.
As welded	58500	80000	24	37	69000	95000	13	12
Strain relieved	70000	81000	27	54	76000	91000	18	20
Annealed	64000	77000	26	53	69000	87000	17	20

The properties of the weld metal are of the same general order as those of the parent metal and, like the latter, they tend to increase their tensile properties upon heating and cooling.

Full Thickness Cold-Bend Specimens

Condition of Material	0.08% C Plates and Wire Bend	Elongation	Fracture	0.20% C Plates and Wire Bend	Elongation	Fracture
As welded	180	40	None	45	14	Complete
Strain relieved	180	42	None	180	31	5/16-in. crack through weld
Annealed	180	42	None	180	32	

The bending ability of the 0.08% carbon Yoloy coupons is a very satisfactory one and compares favorably with that of mild carbon steel welds. The bending quality of the 0.20% carbon Yoloy coupons, while of a somewhat lower order, is still within limits considered acceptable even for mild carbon steel, as specified by the code.

Inspection of Welded Seams in Pressure Vessels*

By WM. D. HALSEY†

THE suspicious attitude toward fusion welded pressure vessels that has been very prevalent in the past and exists in some degree at the present time has resulted because of failures of such vessels, which in many cases have caused extensive property damage, loss of life and personal injury. In reviewing those accidents it may be said that, in general, they were caused by unsound welds. The term "unsound" in this connection relates not to weld *metal* of poor physical properties, but to a fusion welded joint in which the weld metal was not properly fused to the base material. In other words, there was no adequate bond between the weld metal and the plate.

It should not be understood that failures have never occurred because of poor weld metal. For proper distribution of the stresses in a welded joint, the weld metal should have approximately the same physical properties as the base metal. This requirement is particularly true as regards ductility since the stresses resulting from the cooling of a molten mass of metal, as in a weld where movement is restricted by the adjoining rigid material, are severe and if cracking of the weld is to be avoided, it is essential that the weld metal have ductility. As a matter of fact the welding of heavy walled pressure vessels was not feasible from a practical standpoint until the advent of the high ductile weld metal available today.

With any of the usual methods of welding now in use, weld metal of adequate tensile strength will be obtained if the weld is sound, that is to say, is free from slag, and is reasonably clean. Some methods of welding may produce joints of higher tensile strength than others, but with the factors of safety in common use the tensile strength of the weld metal itself is of comparatively minor interest.

On the other hand, weld metal of adequate tensile strength and ductility will be of no value if that metal is not properly fused to the base material. Illustrations almost without end could be given of fusion welded vessels that have failed. An examination of such failures has almost invariably shown an unsound weld, that is to say, one that was not fused to the base metal either because of a mere casting of the metal in the welding groove or because of slag being entrapped between the weld metal and the base material. An illustration of one such failure is shown in Fig. 1. The vessel in this case was a fusion welded brine cooler in an ammonia refrigerating system. The vessel was 42 in. in diameter and 16 ft. long. It had been in service for about twelve years when it suddenly tore through the fusion welded longitudinal seam. From the information that was subsequently obtained, failure apparently took place at very little more than the normal working pressure, causing property damage of $8000, killing one man and injuring two others.

After the accident, specimens were cut from the longitudinal welded seam, polished and etched. These etched specimens are shown in Fig. 2 from which it will be clearly seen that there was an extensive lack of fusion. The failure of the welded seam occurred partly between the weld metal and the plate and partly through the weld itself.

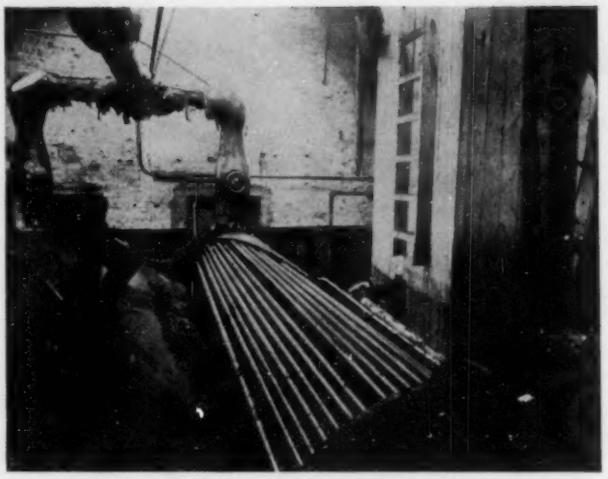


Fig. 1

Welds that are seriously defective are caused almost invariably by lack of control of the welding procedure or inadequately trained welding operators. It is the intent of most of the Codes relating to welding to reveal inherent defects in methods of welding and lack of ability on the part of operators. This statement is particularly true of the A. S. M. E. Code for Unfired Pressure Vessels. However, before the adoption of that Code many fusion welded vessels had been built and there was often but little, if any, knowledge on the part of manufacturers of a proper procedure for welding or the ability of the operators. Furthermore, a great number of fusion welded vessels being built today are not constructed in accordance with the Code requirements. All such vessels have given insurance companies great concern because unfortunately no one can determine the soundness of a welded joint by mere visual examination of its exterior surface.

The company which the writer represents has recently investigated a number of questionable fusion welded vessels by trepanning plugs from the welded seams and etching these plugs to detect lack of fusion or slag inclusions.

The tool used for the purpose is shown in Fig. 3. While similar tools have been on the market for some time, it is only recently that the cylindrical saw has been available in high speed steel and a tool that will withstand severe service is quite necessary for this kind of work.

A problem that was presented in using a tool of this kind was the retention of the plug after it had been severed from the vessel and for this purpose a special split

* Presented at November 20th Meeting, Pittsburgh Section, AMERICAN WELDING SOCIETY.

† Asst. Chief Engineer, The Hartford Steam Boiler Inspection and Insurance Company.

pilot or mandrel was developed as shown in Fig. 4. With such a pilot the plug is retained and withdrawn from the vessel with the hole saw or trepanning tool as shown in Fig. 5. The plug is then sectioned, polished and deep etched in a boiling solution of equal parts of hydrochloric acid and water.

By using the proper size of tool it is a simple matter to close the opening in the vessel by tapping the hole and screwing in a pipe plug.

Some examples of plugs that have been cut from questionable vessels will undoubtedly be of interest. Figure 6 shows some specimens removed from a fusion welded ammonia brine cooler which had been in service for several years. It is interesting to compare these plugs with the etched cross section of the weld shown in Fig. 3. What might have happened if the vessel, from which the plugs were cut, had remained in service may readily be conjectured.

Figure 7 shows some plugs cut from a fusion welded ammonia generator in an absorption system. After seeing these plugs the owner decided to replace the vessel.

Figure 8 shows some plugs cut from a fusion welded soap kettle. Not only were there poor penetration and fusion, but cracking of the weld had also taken place.

A large number of vessels have been examined by this method and in the great majority of cases the welds have been found defective to some extent. In many cases the defects were so extensive that the vessels were considered to be in a really dangerous condition for operation and were either retired from service or satisfactorily repaired.

It may be argued that in cutting plugs from a vessel specimens might be obtained that do not represent the true condition of the welded seam. It has been the practice, however, to cut not one but several plugs from each vessel. Invariably, the same degree of defectiveness or soundness has been revealed in all plugs. It is hardly conceivable that a welded seam could be dangerously defective and not have that condition exist to a degree, at least worthy of consideration, throughout its entire length.

It has also been claimed that the drilling of holes in the welded seam weakens the vessel. However, if the vessel is operating with a reasonable factor of safety no measurable weakness has been introduced if the seam is sound, and if it is not, then the vessel should not be operated at all. With the size of holes that are used for examination of welded seams no one would hesitate to

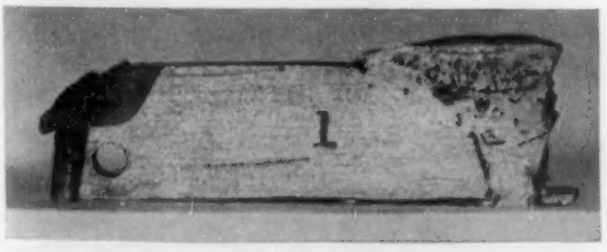


Fig. 2

Fig. 3

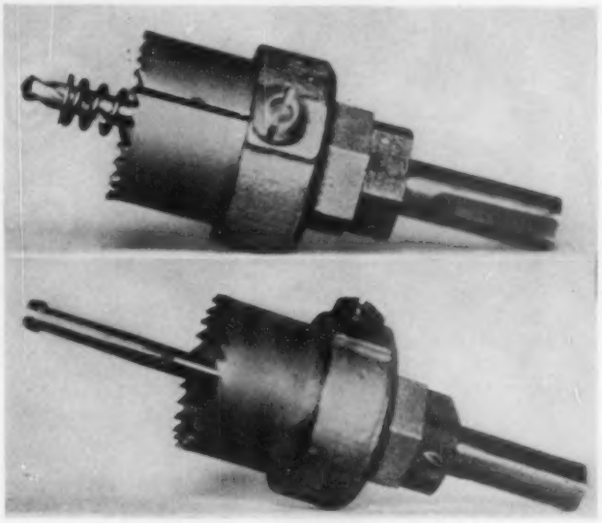


Fig. 4

make a pipe connection to the vessel by drilling and tapping the shell in the solid plate. Why, then, be concerned with such an opening in a sound weld?

Turning now from the "antiques" and "non-code" construction, consideration may be given the methods now employed for the qualification of welding operators. There is today a strong and well justified feeling that the methods in various codes for the qualification of operators are too expensive and it is the writer's belief that such methods have gone too far in one direction and not far enough in another.

The tensile strength and ductility of deposited weld metal is determined entirely by the materials used and the proper control of the process. Those physical properties should be determined through an investigation of the process itself by making and testing welds fabricated with all essential variables under careful control. On the other hand, the reliability of a *welded joint*, provided proper materials have been used and a proper procedure followed, depends entirely upon the fusion between the weld and base metals. The matter of obtaining that fusion lies wholly in the hands of the welding operator. Therefore, when the welding procedure is properly controlled, it is unnecessary to test welding operators for tensile strength and ductility and, in this respect, qualification tests have gone too far. What should be determined is the operator's ability to follow and apply the given procedure so as to make a sound weld, and for this purpose some simple tests will suffice. Such tests, however, should be extended to an examination of the operator's ability to make sound welds of the type he is to fabricate in actual construction. Usually, simple bending or breaking tests will be adequate.

For the qualification test of a welding operator to be employed in the fabrication of the longitudinal or circumferential seams of welded pressure vessels where the work is all done in the flat position, the making of a weld in the flat position and of the kind to be used in construction, whether of the single or double butt, or lap type, is sufficient.

Operators who are to be employed in construction where position welding is done should be required to make welds of the same type and in the same position as will be encountered in actual construction.

Pipe line welding operators should make welds between two pieces of pipe, the axis of which may be in either the horizontal or vertical position with the pipe

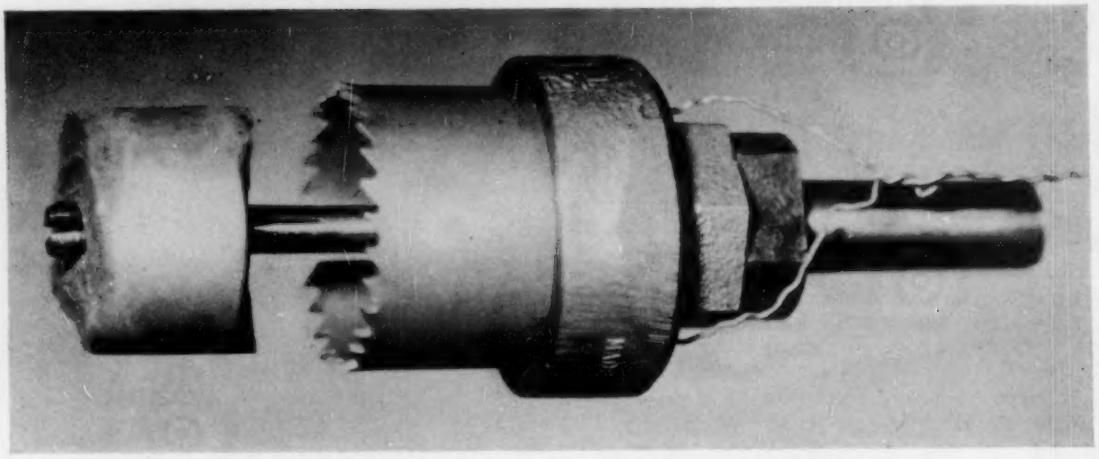


Fig. 5

either rolled or fixed in position while the weld is made, depending on the conditions that will be encountered in actual construction.

It may not follow, however, that a welding operator who has shown ability to make a rolling or fixed position pipe weld can make a sound weld when fabricating a pipe fitting. This fact has been well demonstrated by a number of tests that have recently been made of fusion welded pipe fittings. These fittings were cut into numerous cross-section specimens which were then etched. The result of some of these examinations are shown in Figs. 9 and 10.

It is now the practice of one very prominent manufacturer of fusion welded pipe fittings to qualify operators by having them make representative pipe fittings and cutting these apart for etching.

This same method of examination of unusual construction which cannot be tested by other means such as bending or breaking is extremely valuable in developing the proper method of welding of such specimens and in enabling the welder to visualize what he is doing.

The question as to how often a welding operator should be given a qualification test is one that has been debated frequently and at great length. The A. S. M. E. Code for Unfired Pressure Vessels calls for a re-qualification test every six months unless the operator is continuously employed on the same type of work in which case a qualification test once each year is sufficient. On the other hand, it is conceivable that a man might be qualified today and within the next few days develop some organic trouble such as an injury to the eye which would make it impossible to him to make a sound weld, yet that condition would not be detected for six months or possibly a year. Furthermore, when making a weld for qualification purposes the operator is using every care and he may not feel it necessary to observe such care in actual production work. A procedure which constantly checks the operator's ability to make a sound weld is what is really desired. Such a check is obtained, of course, when fusion welded vessels are X-rayed as required for U-68 vessels and power boiler drums.

While the discarding of the requirement for tension and ductility tests in the qualification of a welding operator together with the adoption of improved methods of checking for soundness would very greatly decrease the expense involved and at the same time give better information than is now being obtained, it would not dispense with the present requirement of most codes that operators must undergo subsequent tests at periodic intervals. Furthermore, such retests, however frequently they are made, are not a constant check on the operator's daily work.

For U-69 and U-70 vessels the Unfired Pressure Vessel Code requires only that the welding operators be qualified. If, on such vessels, the practice of trepanning plugs from welded seams were adopted as a requirement in shop inspection a constant check would be made at relatively small expense and as long as the welding operator showed an ability to make a sound weld by such a test it would be unnecessary to call for any periodic qualification tests. Such a procedure would be far more positive than the present practice of depending entirely upon qualified operators. It would, of course, be necessary that the welding operator make a satisfactory test weld before being permitted to engage in actual construction.

Test holes cut in the welded seams of pressure vessels as a requirement for shop inspection may be closed by welding so that the seam would be intact.

Should it happen that any one plug out of several removed from a vessel were to reveal an unsound condition, two additional plugs could be removed nearby the

Fig. 6

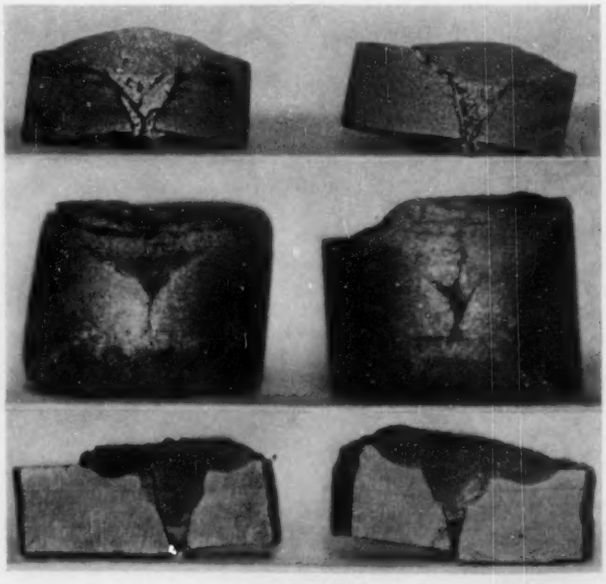


Fig. 7 (Center)

Fig. 8 (Lower)

questionable point and if such plugs showed a sound weld the vessel could be accepted as satisfactory.

If this suggested procedure were adopted, not only would the expense of qualifying welding operators be very greatly reduced but there would be much greater assurance of the soundness of the welded seams.

Fig. 9

Fig. 10

Arc Welding in Argon Gas*

By GILBERT E. DOAN AND WILLIAM C. SCHULTE**†

During the course of the extensive research in arc welding being conducted at Lehigh University under joint sponsorship of the A. I. E. E. and several other organizations, apparatus for experimental welding at atmospheric pressure in controlled pure gas atmospheres has been designed and constructed. Tests in argon gas reveal 3 phenomena not previously associated with the welding arc: (1) the impossibility of maintaining a stable arc in highly purified argon under ordinary conditions; (2) the absence of all crater formation under pure iron in pure argon; (3) the absence of all observable "pinch effect" accompanying the detachment of the globules from the electrode wire.

AN extensive program of investigation is being carried out at Lehigh University in the study of arcs and arc welds of pure iron. These studies have been sponsored by A. I. E. E. and aided by The Engineering Foundation. Several reports on the progress of these studies have been issued previously.[1–4] The present report discloses the design and construction of an apparatus for experimental welding at atmospheric pressure in controlled pure gas atmospheres, using automatic feeds for both electrode and work piece. Auxiliary apparatus is provided for purifying the gases and for analyzing them, both before welding begins and after it is completed. This apparatus design may be useful to other investigators in the study of welding atmospheres.

Briefly summarized, the more important results obtained so far are as follows:

1. Stable welding arcs cannot be maintained in argon of 99.5 per cent purity, when the electrode is clean, unless the open-circuit voltage is greater than 62 volts and the short-circuit current greater than 110 amperes. In air or in impurer argon stable arcs form readily at currents and voltages far less than these minima.

2. No crater is formed under the iron arc in argon. This condition results in complete lack of penetration into the base metal, and thus renders welding impossible.

3. The globules at the end of the electrode grow gradually to about $^1/_4$ inch in diameter and detach under no apparent force except that of gravitation.

4. The melting rates per kilowatt-hour in argon and in air are approximately equal.

Among the most important metallurgical aspects of the investigation are the high ductility of the pure iron welds made in argon: 90 per cent reduction of area and 30 per cent elongation. For pure iron welds made in air the reduction of area was only 3.5 per cent instead of 90, and the elongation only 4 per cent instead of 30. These results indicate the great effect of air in lowering the ductility of the metal obtained in the arc welding operation. The strength of the pure iron welds on the contrary was 40,000 pounds per square inch for those made in argon and rose to 65,000 for those made in air. The effect of the air thus is to raise the strength of the weld greatly. Some experiments made with cellulose coating on the electrode gave results intermediate with respect to those in argon and those in air. Other purely metallurgical aspects of the investigation are to be reported elsewhere.

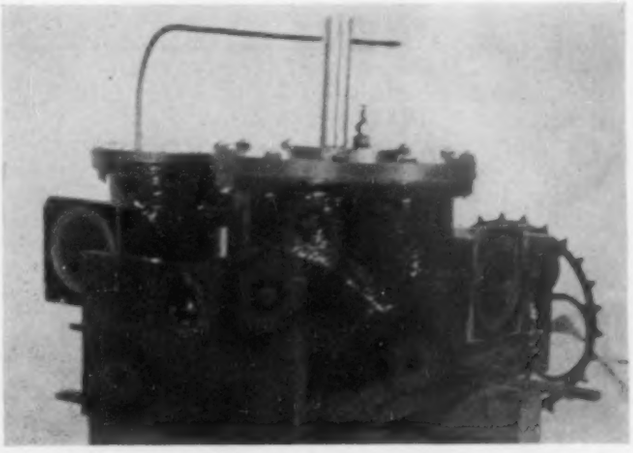


Fig. 1—Exterior View of Chamber for Experimental Welding in Pure Gases

* A research progress report written especially for *Electrical Engineering*. Manuscript submitted March 22, 1935; released for publication July 25, 1935. A contribution to the Fundamental Research Committee. Presented at Fall Meeting of A. W. S., Chicago, Oct. 1, 1935.

** Both of Lehigh University, Bethlehem, Pa.

† Formerly Engineering Foundation Fellow at Lehigh University, Bethlehem, Pa.; now with Lukens Steel Company, Coatesville, Pa.

[1] G. E. Doan and J. L. Myer, "Researches in Arc Welding," *Elec. Engg.*, Vol. 51, Sept. 1932, pp. 624–7.

[2] G. E. Doan and J. L. Myer, "Arc Discharge not Obtained in Pure Argon Gas," *Phys. Rev.*, Ser. 2, Vol. 40, April 1, 1932, pp. 36–39.

[3] G. E. Doan and A. M. Thorne, "Arcs in Inert Gases. II," *Phys. Rev.*, Ser. 2, Vol. 46, July 1, 1934, pp. 49–52.

[4] "Arcs in Inert Gases," *Phys. Rev.*, 1935.

Material Used

The rods and plates used in this program were of carbonyl iron which had been treated in a stream of undried hydrogen for 72 hours at 1375 to 1420° C., by a cooperating laboratory, that of the General Electric Company at Schenectady, N. Y. The wire was 4 millimeters ($^5/_{32}$ inch) in diameter and the base metal plates were 6 and 2 millimeters thick. These plates were used to line a 45-degree V groove between two $^1/_2$-inch steel plates, the plates serving as backing to prevent the arc from melting through the pure iron "liners" and from "blowing" magnetically. This arrangement is shown at *V* in Fig. 3. The chemical analysis of the carbonyl iron after hydrogen treatment was as follows:

Carbon	0.009	Sulphur	0.005
Manganese	0.046	Nitrogen	0.002
Silicon	0.002	Oxygen	0.002
Phosphorus	0.01	Hydrogen	0.0002

The analyses were supplied by another cooperating laboratory, that of the American Rolling Mill Company; all values given are percentages.

Most of the tests were made using bare wire. In a few instances, the wire was coated to produce a "shielded arc" such as has recently yielded commercially a weld metal of markedly improved properties. The coating contained cellulose with sodium silicate as a binder and some titanium oxide to reduce porosity and act as an arc stabilizer. These rods were coated by courtesy of the welding research laboratory of the A. O. Smith Corporation.

The argon used was supplied by the incandescent lamp department of the General Electric Company. As received, the gas contained approximately 1 per cent nitrogen. All carbonaceous gas impurities were less than 30 parts per million. The argon was given final purification after being admitted to the welding chamber and when analyzed just before using, it showed a purity of 99.3 to 99.6 per cent argon.

Description of Apparatus

Figure 1 shows the chamber in which the tests in pure argon were made. Figures 2 and 3 show the main details of construction. The welding chamber is built of copper tubing $7^1/_2$ inches in diameter and $^3/_{32}$ inch thick to provide good heat conduction. It consists of a vertical tube *A* 6 inches high cut to fit into a horizontal half cylinder *B* 15 inches long. The bottom and ends of the horizontal part are made from copper plates. The top of the vertical tube is fitted with a flat cover plate *C* $^1/_2$ inch thick. The cover plate can be bolted securely to the top of the vertical tube with a rubber gasket between to prevent leakage. A suitable window is provided for viewing the welding operation.

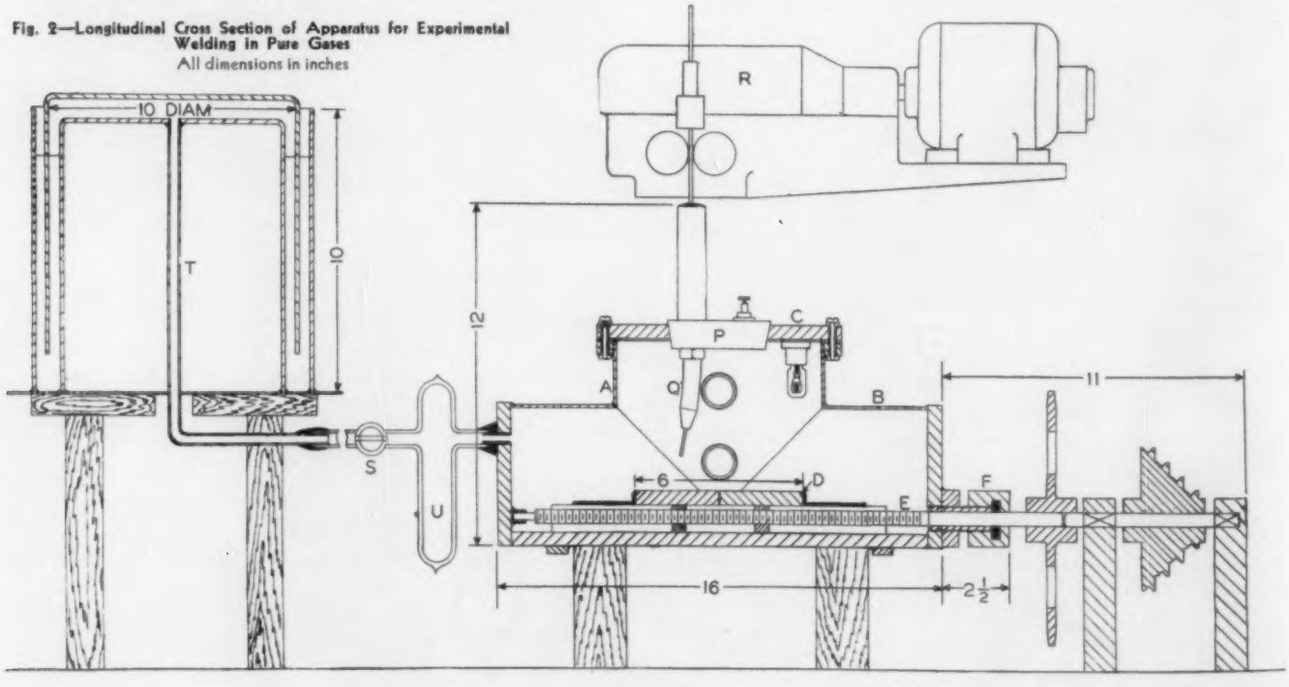
Specimens to be welded are placed on a movable table *D* on the bottom of the chamber. The table is moved by a lead-screw *E* which is driven through a stuffing box *F* by a $^1/_4$-horsepower variable-speed motor.

An auxiliary chamber 4 inches in diameter and 6 inches high is connected to the rear of the welding chamber with 2 horizontal tubes *G* each 1 inch in diameter. This auxiliary chamber contains a "misch-metal arc" (*H–I*), a glow discharge between an iron anode (*I*) and a "misch-metal" cathode (*H*). ("Misch metal" is a pyrophoric alloy containing about 65 per cent of rare earth metals, such as cerium and lanthanum, the balance being iron.) Such a discharge activates the cathode so that it combines with any chemically active gas surrounding it, thus purifying the inert atmosphere used in these experiments. The connection to the argon tank and the vacuum pump is made to the top of this auxiliary chamber so that all the argon admitted is made to pass the misch-metal arc before passing into the welding chamber.

Figure 4 shows the seal that allows the welding rod to pass into the chamber and yet not allow air to leak in or argon to leak out. Two soft rubber washers *J* are compressed between parts *K* and *L* by turning *K*. The soft rubber fits tightly around the rod and against the walls of the tube *M*.

To evacuate the system tube *N* is sealed to the copper plug *P*. A split collar *O* fits tightly around the rod and into the small hole on the top of the tube *N*. This joint is entirely sealed with "picein," a black wax commonly used in high vacuum work for sealing joints in the apparatus. After argon has been admitted and is up to atmospheric pressure, the picein and split collar

Fig. 2—Longitudinal Cross Section of Apparatus for Experimental Welding in Pure Gases
All dimensions in inches



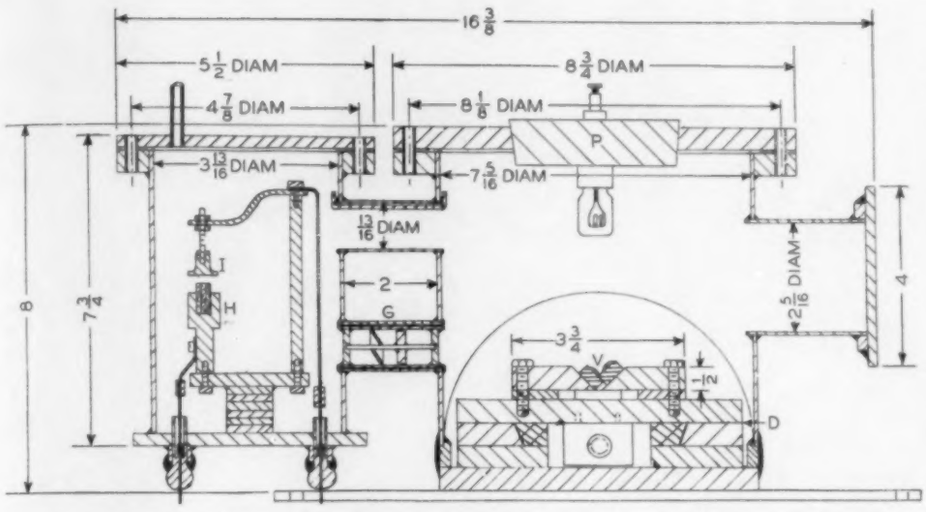


Fig. 3 (Above)—Cross-Sectional View of Welding Chamber

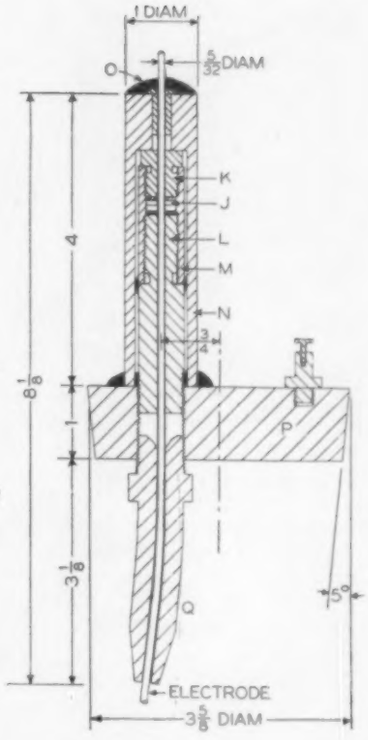


Fig. 4 (Right)—Cross-Sectional View of Welding Electrode Seal
All dimensions in inches

are removed and the rod thoroughly cleaned of picein with ether.

The copper plug P fits into a tapered hole in the cover plate of the main arc chamber, and the tapered joint is sealed with stopcock grease. The rod passes through this copper plug $^3/_4$ inch off center, thus providing a means for shifting the electrode from one side to another.

The current pick-up nozzle Q is fitted to the bottom of the tapered copper plug. The rod is fed into the chamber with an automatic welding head R.

During welding, the argon expands considerably because of the heat of the arc. To accommodate this expansion, a gas reservoir was built which consists of a gas-tight container floating over vacuum pump oil. Figure 2 shows the details of construction. When evacuating the system, stopcock S is left open until the oil level is raised on the inside of the floating container and oil flows down tube T and into the glass reservoir U. The stopcock then is closed and is left closed until the chamber has been filled with argon to atmospheric pressure and the argon has been cleaned by the misch-metal arc.

For those welds that were made in air, the movable table, of course, was mounted in the open directly under the welding head.

In order to know quantitatively the purity of the gas before and after welding in it, a gas analyzer was built which was patterned after that proposed by Severyns, Wilkinson and Schum.[5] Figure 5 shows the construction. It consists of a small glass vessel in which a small quantity of lithium can be heated. The mixture of gases to be tested is admitted to the vessel and the pressure is measured with an open-end U manometer. After heating the lithium for 45 minutes in the presence of the gas to be tested the gas is cooled to the same temperature as before and the pressure measured again. The percentage of impurity is expressed as:

$$\frac{P_1 - P_2}{P_1} \times 100 = \text{per cent impurity}$$

where P_1 is the pressure before heating and P_2 is the pressure after heating.

Method of Welding

After the system has been evacuated, it was flushed once with argon and again evacuated. The argon for the final filling was admitted very slowly. After an argon pressure of approximately 2 to 4 millimeters of mercury was obtained, the misch-metal arc was started. A period of 30 to 45 minutes was allowed to bring the system to an atmospheric pressure of argon. It has been found by other experimenters that misch-metal arcs are more efficient scavangers when the argon is admitted slowly. It was found also that if the argon was admitted in less than 15 minutes the misch-metal arc would become very unstable and go out. If this occurred it was impossible to start the arc again until the pressure had been reduced to 10 to 20 millimeters.

After the argon had been admitted and the system was at atmospheric pressure, the misch-metal arc was allowed to run for 6 to 8 hours. During this time the gas was given a positive circulation by means of a small fan and motor placed in the lower tube connecting the misch-metal and welding chambers.

At the end of the purification period the misch-metal arc was turned off and the picein seal around the welding rod was removed. The welding in argon was done with a current of approximately 180 amperes and an arc voltage of 10 to 12 volts. The arc length could be controlled very closely and was kept at approximately $^1/_8$ to $^3/_{16}$ inch at all times by means of the automatic feed of the welding head. For the welds made in air with the bare pure iron electrodes a current of 150 amperes was used with an arc of 15 to 17 volts. When welding with the heavily coated pure iron electrode 130 to 140 amperes was used with 25 to 28 volts. These conditions were the necessary ones for each type of weld in order to obtain sound nonporous welds.

Welding Characteristics Observed in Argon

Deposition of metal in an atmosphere of argon is strikingly different in appearance, for both pure iron and steel, from what it is in air. While the melting rates in argon and in air are similar (argon 0.922 pound per kilowatt-hour, air 0.895 pound), yet the transfer of metal in argon takes the form of very large globules approximately $^7/_{32}$ inch in diameter at the rate of about 1 every 3 seconds, whereas in air the globules are quite

[5] J. H. Severyns, E. R. Wilkinson and W. C. Schum, "Use of Metallic Lithium in Analysis of Gases," *Ind. & Eng. Chem.*, Analytical Ed., Vol. 4, Oct. 15, 1932, pp. 371–3.

small and fall at the rate of about 10 to 15 per second. The globules in argon cross the arc calmly and under no apparent force except that of gravitation. Quite frequently they grow so large as to bridge the arc and then they free themselves from the electrode quite rapidly. The so-called "pinch effect," proposed by Carl Hering and studied by E. F. Northrup, is not manifest in promoting globule detachment in the iron arc in argon, even when the drops grow to a very large size before detaching. The arc is quiet, with a complete absence of the steady sharp crackling sound that is characteristic of a good welding arc in air. When viewed through the dark yellowish green welding glass, the arc core appears bright yellow with successive sheaths of greenish blue, black and orange.

Another striking and significant difference when welding in argon is the complete absence of the crater in the liquefied base metal or previous weld bead that is so important for welding in air. This results, of course, in a complete lack of penetration into the parts. Figure 6 shows the appearance of the welding arc in argon and the lack of crater formation. Figure 7 is a macrograph of a section of a multipass weld of ordinary steel made in pure argon. The lack of penetration is clearly evident since the contour of each individual layer easily can be traced.

Thus one of the most basic and essential features of the commercial arc welding process, namely, penetration and crater formation, is not an inherent characteristic of the iron arc, but, fortunately for the engineer, it is one that appears when arc welds are made in air. This absence of crater formation is of peculiar interest since numerous theories have been advanced to explain the nature of the force in the arc that creates this crater, and yet none of these theories considered the atmosphere as an important factor. One theory, proposed by P. P. Alexander and G. Donath, is that a pressure within the arc is created by a gas or electron steam and that this pressure blows the liquid metal outward from the center of the molten puddle toward its edges. One of the authors in an earlier study[6] has attributed the forces of crater formation partially to the differences of surface tension of the molten metal at the center of the puddle from that at the edges. Neither of these theories would account for the lack of crater formation found for iron arcs in argon.

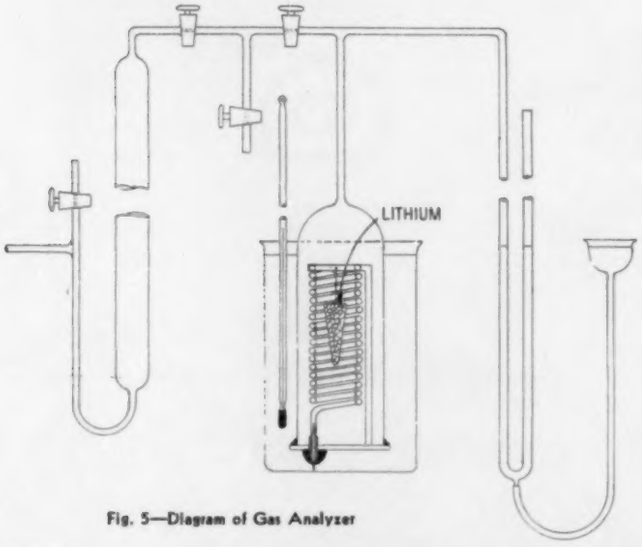


Fig. 5—Diagram of Gas Analyzer

[6] G. E. Doan, "Concerning Crater Formation," Am. Welding Soc. Jl., Vol. 2, July 1932, pp. 17–18.

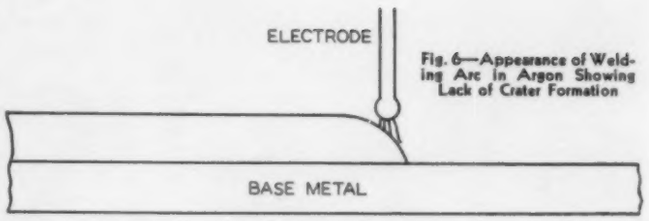


Fig. 6—Appearance of Welding Arc in Argon Showing Lack of Crater Formation

An attempt was made to find out what percentage admixture of air was necessary in the argon in order to obtain penetration and fusion. When welding in 50 per cent air and 50 per cent argon, the penetration was about equal to that obtained in air. Welds then were made in 90 per cent argon and 10 per cent air. Figure 8 is a macrograph of a section of such a weld. A slight amount of penetration can be noted, and there was a very shallow crater at the end of the weld bead. Hence it can be seen that crater formation is dependent on the presence of air and that very little air is required to produce penetration and crater formation. The experiments in penetration were carried out by an expert in experimental arc welding, and every possible combination of current, voltage, arc length and rate of travel was tried until the best result achievable was obtained in each gas mixture. Figures 7 and 8 show a single cross section of the results. They are, however, entirely representative of the welds as a whole.

Unstable Arcs in Argon

One of the authors and J. Leland Myer have reported[2] that an arc discharge could not be obtained under ordinary conditions in pure argon gas. Further studies with Albert M. Thorne[3] have confirmed this fact for other inert gases and have yielded knowledge of the boundary conditions of the nonarcing phenomenon. These studies were carried out with low current arcs, that is, from 1 to 10 amperes. In the present investigation the arc voltage and current were within an entirely different range, that is, from 40 to 180 amperes. In this range also nonarcing was observed under certain conditions both with commercial steel wire and with pure iron wire.

Table 1—Results of Welding Tests in 99.3 to 99.5 Per Cent Pure Argon Gas

Rod material: commercial steel wire *E*-No. 1-*A* 1/8 inch in diam.

Weld No. and Pass	Welding Current Amperes	Welding Volts	Open-Circuit Volts	Short-Circuit Amperes	Rod Polarity	Rod Surface	Stability of Arc
14–1	40–60	26	58–60	110–120	–	Clean	Fairly stable
14–2	40–60	26	58–60	110–120	–	Clean	Unstable
14–3	40–60	26	58–60	110–120	–	Clean	Unstable
14–4	40–60	26	58–60	110–120	–	Clean	Unstable
14–5	40–60	26	62–64	110–120	–	Clean	2 to 10 seconds
14–6	40–60	26	62–64	110–120	–	Clean	2 to 10 seconds
15–1	70	14	60	110–120	+	Clean	Unstable
15–2	70	14	60	110–120	+	Clean	Unstable
15–3	70	14	65	110–120	+	Clean	5 to 10 seconds
15–4	70	20	80	110–120	+	Clean	Stable
15–5	50–70	14–17	58–60	110–120	–	Clean	Unstable
15–6	120–160	24–30	63	200	–	Clean	Stable
15–7	70	14	60	110–120	–	Sull	Stable
15–8	70	14	60	110–120	–	Sull	Stable
15–9	120	18	63	200	–	Sull	Stable

Negative Electrode Coating Removed.—When welding with commerical steel wire of 1/8-inch diameter with the "sull" coating (the light sulphate coating left on the wire after pickling in sulphuric acid) removed, and with a welding current of 40 to 60 amperes and an arc voltage of 26 volts, after the arc had been maintained for a short

time (30 to 50 seconds) it became very unstable. The electrode would be fed down by the automatic device, make contact with the plate and then be drawn away. When the contact with the plate was broken a flash of an arc would occur lasting for only a fraction of a second and then would go out. The welding head automatically would move the electrode down again and the same process would be repeated. This would occur 8 or 10 times until finally an arc could be struck that would last for a few seconds, and when it went out the same cycle would be repeated. This took place when the open circuit voltage of the welding generator was 58 to 60 volts with momentary short-circuit currents of 110 to 120 amperes and the polarity of the electrode negative. The instability was not attributable to the commonly observed magnetic effect encountered at the ends of the plate, for it would take place in the center portion of the weld as well as toward the ends. When the open circuit voltage was increased slightly above 60 volts (62 to 64) the arc would last for several seconds before going out. When making the test welds in argon this unstable range was avoided by increasing the open circuit voltage of the generator to 65 volts or more and by increasing the welding current.

Positive Electrode Coating Removed.—When the polarity was reversed, that is, with the electrode positive (and cleaned of all drawing compound as before), the arc was again slightly unstable with open circuit voltages of 58 to 60 volts and momentary short-circuit currents of 110 to 120 amperes. During the short welding periods the arc voltage was 17 volts with a welding current of 50 to 70 amperes. When the open circuit voltage was increased to 65 volts there still were periods of nonarcing,

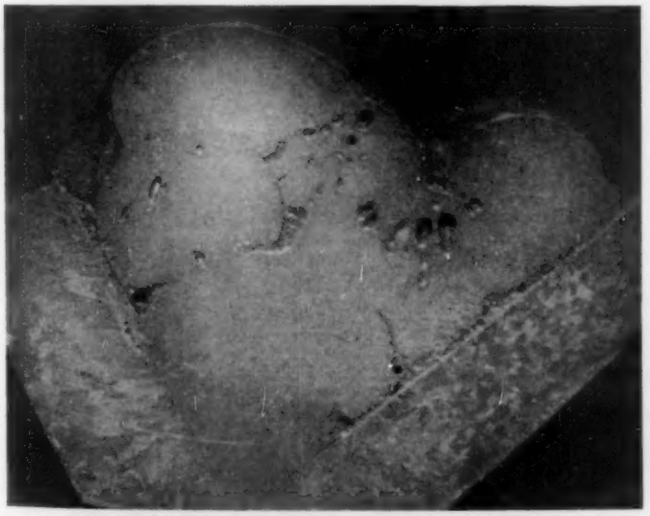


Fig. 7—Cross Section of Multipass Weld of Ordinary Steel in Pure Argon Gas. Note Lack of Penetration into Plate and into Early Deposits

Fig. 8—Same Welding Conditions as Fig. 7, but in a Mixture of 90 Per Cent Argon and 10 Per Cent Air. Note Slight but Definite Penetration into Plate

but when increased beyond this the arc persisted until stopped.

Negative Electrode Coating Remaining.—When the sull coating was allowed to remain on the commercial steel electrode and the electrode polarity was negative, the arc was fairly stable with an open circuit voltage of 58 to 60 volts and momentary short-circuit currents of 110 to 120 amperes. This gave values of 14 to 17 volts and 70 amperes for welding conditions. When these values were obtained the arc would emanate from the surface of the molten globule at the end of the electrode only.

The condition of the surface of the electrode thus had a pronounced effect upon the arc characteristics when welding in argon. When the rod has been cleaned of its sull coating and drawing compound, and when the electrode polarity is made negative, the arc will travel up the side of the electrode for a distance of $^1/_2$ to $^3/_4$ of an inch. This behavior made welding very difficult, for while the arc would be emanating from the side of the electrode, the arc voltage would be high and the welding head automatically would feed the rod down to lower the voltage, until finally the end of the rod would ram into the base metal and cause a complete short circuit. However, this same phenomenon did not take place when the electrode polarity was positive, but the arc then would jump around on the plate in a very erratic manner. When the electrode was negative and the sull coating remained on the rod, the arc emanated steadily from the end of the electrode only. Evidently the cathode is unstable, whether it be formed of the wire or the plate, unless the wire is coated. In this event the cathode is stable. Results of these tests are summarized in Table 1.

These observations on lack of penetration and crater formation and lack of arc stability indicate that intrinsically the high current arc is something quite different from that with which we have become acquainted by observing only the arc between steel electrodes in air. Other purely metallurgical aspects of the investigation are to be reported elsewhere.

Tests to Determine the Feasibility of Welding the Steel Frames of Buildings for Complete Continuity*

By W. M. WILSON†

I. Introduction

1. *Object and Scope of Investigation.*—Tests indicate that welded connections for beams, even when intended to resist shear alone, are so nearly rigid that they introduce moment at the ends of the beam and, if they are not designed as a moment-resisting connection, some parts may be overstressed. Moreover, the ability of a connection to resist moment is important, not only because it prevents overstress from the inevitable moment that is produced, but also because it may increase the load-carrying capacity of the beam. For these reasons, the welded connections used in the present investigation have been designed to resist both moment and shear.

Two types of connections have been tested, designated as beam-to-girder and girder-to-column connections, respectively.

The beam-to-girder connections in a building are not usually subjected to either dynamic loads or a reversal of stress and the investigation of these connections has been limited to static tests. Two types of beam-to-girder connections were tested. For one type, the flange of the beam was welded directly to the flange of the girder. For the other, a tension plate connected the flange of the beam to the flange of the girder. The deflection as well as the strength of the connections was determined for all specimens in the static tests.

The joints connecting the girders to the columns of a building frame transmit the vertical shear to the column and, if the connections are rigid, they also resist a moment, which may be due to gravity loads, wind loads or earthquake shocks. The welded connection has, inevitably, a certain resistance to moment and if properly designed can be depended upon to resist the moment that occurs when the end of the girder is restrained. Moreover, the restraint at the end of the girder is an economic advantage, not only in reducing the size of the girder required to resist a given gravity load, but also due to the fact that, in providing for wind load by making all bents wind-resisting,[1] the increase in the column and girder sections over that required to carry the gravity loads only, may be less than it would be if only a part of the bents are wind-resisting. All of the above is merely another way of saying that there are certain economic advantages inherent to a type of building frame in which complete continuity is attained, a fact that is realized and utilized in the design of reinforced concrete frames.

In addition to the advantages due to continuity, the welded girder-to-column connection has an additional advantage due to the fact that a welded connection is more compact than a riveted connection and therefore encroaches less on the clearances in a building.

All of these considerations make it appear possible that a welded joint may have certain advantages over a riveted joint for connecting the girders to the columns of a building providing the connections have sufficient strength and rigidity. The tests reported in this paper have been planned to determine these latter qualities of the welded connections.

Because the moment in a girder-to-column connection may be reversed, some specimens were subjected to static tests and others to reversed-load tests. Both the strength and the deflection of the joints was determined in the static tests; the number of reversals of load required to produce a failure of the connection was determined in the reversed-load tests.

Fig. 1a

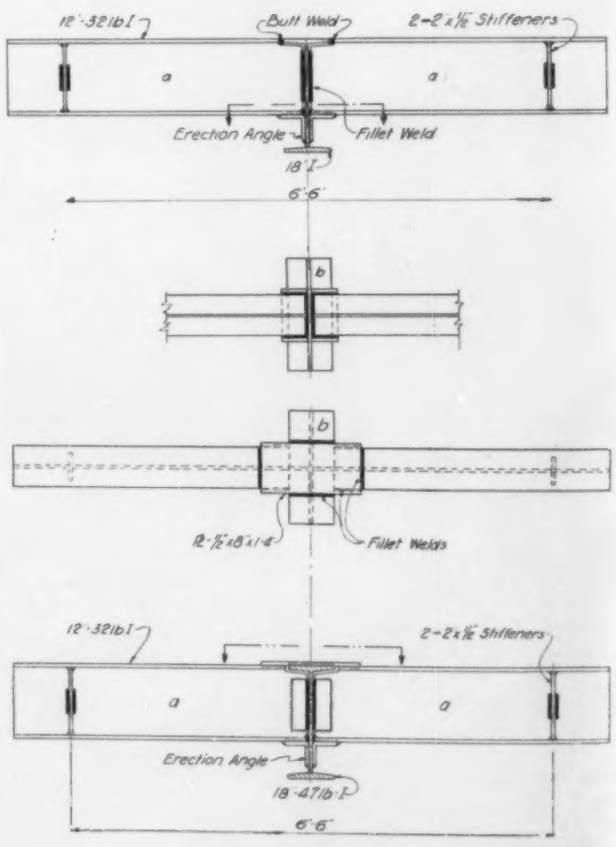


Fig. 1b

* Paper presented at Fall Meeting, AMERICAN WELDING SOCIETY, week of September 30, 1935, in Chicago. Contribution to Fundamental Research Committee, A. B. W.

† Research Professor of Structural Engineering, University of Illinois.

[1] With riveted construction, some buildings are designed with all bents wind-resisting, others are designed with only part of the bents wind-resisting.

TABLE 1

RESULTS OF STATIC TESTS

BEAM-TO-GIRDER CONNECTIONS

SPECIMEN		MAXIMUM LOAD*	MAXIMUM FLANGE STRESS**	δ AT DESIGN LOAD	TYPE OF FAILURE
A71	1/16" TO 1/2" FILLET	118 800	57 000	0.0000	FLANGE BUCKLED
A72	1/4" TO 7/16" FILLET	123 700	59 000	0.0001	FLANGE BUCKLED WELD FAILED
B71	1/16" TO 1/2" FILLET	112 500	54 000	-0.0002	FLANGE BUCKLED
B72	5/16 TO 3/8" FILLET	122 600	59 000	0.0000	FLANGE BUCKLED
A81		82 200	39 400	0.0000	WELD FAILED
A82		106 000	51 000	0.0001	WELD FAILED
B81		102 200	49 000	0.0001	FLANGE BUCKLED WELD FAILED
B82		115 700	55 000	0.0004	FLANGE BUCKLED
M11	SAME AS B82	122 000	58 000		FLANGE BUCKLED
M12		105 500	51 000		FLANGE BUCKLED
M13		118 400	57 000		FLANGE BUCKLED WELD FAILED
M14		122 900	59 000		FLANGE BUCKLED
CB1	CONTINUOUS BEAM	124 000	60 000		FLANGE BUCKLED
CB2		120 300	58 000		FLANGE BUCKLED.

* LBS.

** LBS PER SQ. IN.

II. Static Tests

2. *Beam-to-Girder Connections.*—The general features of the specimens containing a beam-to-girder connection are shown in Fig. 1. Each consists of two 12-in. I beams, *a* and *a*, with a short transverse 18-in. I beam, *b*, inserted between them. The top flange of each *a* beam is connected to the top flange of the *b* girder; and the bottom flange of each *a* beam is connected to the web of the *b* girder. The webs of the beams and girder are connected by welds capable of transmitting vertical shear. The resulting structure is a simple beam which, if loaded as shown in Fig. 2, is capable of resisting both shear and moment over the central portion where the beams and girder are connected. For some specimens the webs of the beams and girders are connected directly as shown in Fig. 1*a*, for others, shear reinforcing plates are provided as shown in Fig. 1*b*. Although the individual specimens vary in detail, continuity in the tension flange is provided by one or the other of two methods, by welding the tension flange of the beams directly to the flange of the girder as shown in Fig. 1*a*, or by the addition of tension plates as shown in Fig. 1*b*. For all connections of the former type, Fig. 1*a*, there was a butt weld, welded from the top side, connecting the tension flange of the beam to the flange of the girder. For some specimens this butt weld was also welded from the bottom side, and for still others there were additional welds connecting the coped top edge of the beam web to the under side of the girder flange. For the type of beam shown in Fig. 1*b*, the tension plate was connected to the beams by means of two fillet welds on the under side of the plate and along the edges of the flange, and by means of a third fillet weld across the end of the plate and across the top of the tension flange of the beam. The plate was connected to the flange of the 18-in. girder by means of two fillet welds, one along each edge of the plate and across the top of the top flange of the girder. For all specimens, the bottom flanges of the 12-in. beams were connected to the web of the 18-in. girder by means of welds across the end and on top of the flange of the 12-in. beam. In addition, the edges of the bottom flange were connected to the shelf angle by means of fillet welds. The *A* specimens were welded with bare electrodes and the *B* specimens with coated electrodes. A detailed description of the individual specimens is given in Table 1, which contains the results of the tests.

The specimen was placed in the testing machine with the beams and girder upside down from the position which they occupy in a building so that when they are loaded in the manner shown in Fig. 2 the flanges will be subjected to the same kind of stress, tension or compression, as in the floor of a building. The deflection of the specimen was measured with a portable dial as shown in the figure.

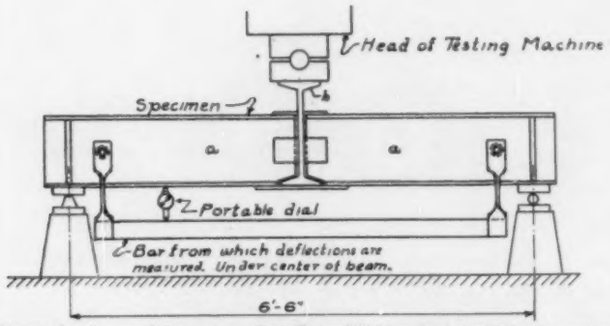


Fig. 2—Specimen and Apparatus. Static Tests of Welds. Beam-to-Girder Connections.

The maximum unit flange stress developed in the 12-in. beam, given in Table 1, is the computed value based upon the maximum load carried by the specimen considered as applied to a simple centrally loaded beam continuous over the central portion and having the same section as the 12-in. beams and having the same span as the specimen. Rotation of the inner ends of the 12-in. beam relative to the transverse girder, designated in Table 1 as θ, will occur if the deformation in the connection is greater than the deformation that would have occurred over the same length if the 12-in. beam had been continuous over the central portion.

A set of typical deflection diagrams for a specimen is shown in Fig. 3 and the relation between the moment and the rotation, designated by θ, is shown in Fig. 4. The values of θ were determined in the following manner.

The computed deflection of a centrally loaded simple 12-in. beam and the measured deflection of the specimen were compared. The difference between the two deflections is attributed to the difference between the behavior of the central portion of the specimen and the behavior of an equal length of a continuous 12-in. beam subjected to the same shear and moment. This difference in behavior is expressed quantitatively for convenience as a rotation between the 18-in. girder and the adjacent end of the 12-in. beam. Numerically it is the quotient obtained by dividing the difference between the two deflections, one measured and the other computed, by one-half of the span of the specimen.

A moment of 732,000 in.-lb. will produce a maximum unit flange stress in a 12-in. beam continuous over the center of 18,000 lb. per sq. in. This moment has therefore been assumed to be the design moment for the beam and has been so indicated on Fig. 4. The values of θ in Table 1 are for this moment.

A description of the individual tests follows:

For Specimen A71 the fillet welds along the edges and across the end of the tension plate varied from $^{7}/_{16}$ to $^{1}/_{2}$ in. and there was no connection between the tension flanges of the two 12-in. beams except through these fillet welds. There were reinforcing plates on both sides of the web to give additional strength in shear. The specimen failed at 118,800 lb., a load for which the computed maximum flange stress is 57,000 lb. per sq. in. Failure was by buckling of the compression flange and there was no indication of failure in any of the welds. The appearance of the beam after failure was similar to that of B72 shown in Fig. 5.

Specimen A72 differed from A71 in the following details. The fillet connecting the tension plate and the flanges of the 12-in. beam were somewhat smaller; there were no shear plates on the web; and the coped top edges of the webs of the 12-in. beams were welded to the flanges of the 18-in. girders, which was not true for A71. The specimen failed at 123,700 lb., a load for which the computed maximum flange stress is 59,000 lb. per sq. in. Failure was due to the breaking of one of the undersized fillet welds, but the compression flange of the beam buckled before the weld failed.

Specimen B71 had the same size and arrangement of welds as A71 but the welds were made with a coated electrode, whereas a bare electrode was used for A71. The specimen failed by the buckling of the compression flange at a load of 112,500 lb., corresponding to a computed maximum flange stress of 54,000 lb. per sq. in.

For Specimen B72 the fillet welds connecting the tension plate to the flanges of the 12-in. beams varied from $^{5}/_{16}$ in. to $^{3}/_{8}$ in. The coped tension edges of the webs of the 12-in. beams were welded directly to the flanges of the transverse 18-in. girder and the ends of the tension flanges of the 12-in. beams were also welded directly to the flange of the 18-in. girder from the under side. The specimen failed by the buckling of the compression flange at a load of 122,600 lb., corresponding to a computed maximum flange stress of 59,000 lb. per sq. in.

Specimens A8 and B8 differed from A7 and B7 in that no tension plate was provided. Specimen A8 was welded with a bare electrode and B8 with a coated electrode. The details of the specimen are shown in Fig. 1*a*.

In fabricating the specimens, the tension flanges of all 12-in. beams were coped to fit the transverse 18-in. beams but the ends and edges to be welded had no other machine work done on them. The compression flange of each 12-in. beam was connected to the shelf angle with two fillet welds, one on each edge of the flange; and the end of the compression flange was connected to the web on the top of the flange. For all specimens, the tension flange of the 12-in. beam was connected to the flange of the transverse 18-in. girder by means of a butt weld welded from the top. For the other portions of the connection there were some variations among the individual specimens and these are described for each specimen in

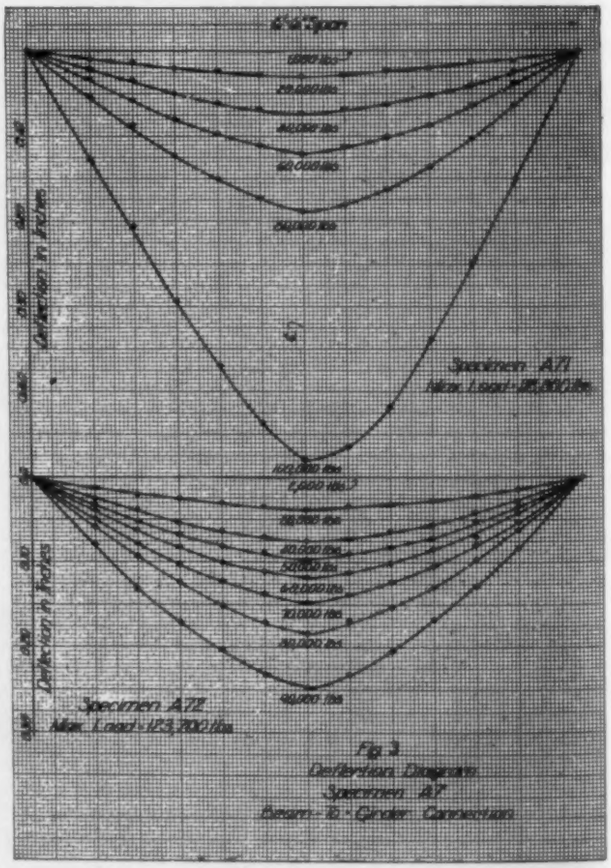


Fig. 3
Deflection Diagram
Specimen A7
Beam- to -Girder Connection

connection with the description of the individual tests which follow.

For Specimen A81 the only welds that were provided were those described in the general description of the specimen contained in the previous paragraph. That is, the only connection for the tension flange was the single butt weld welded from the top, and as the pieces were not scarfed the conditions were not favorable for good penetration. The specimen failed due to the failure of the weld in the tension flange at a load of 82,200 lb. The fracture showed that the penetration did not exceed one-half of the thickness of the thinner of the two flanges being joined.

Specimen A82, in addition to the welds common to all of the A8 and B8 specimens and described in a previous paragraph had a weld connecting the coped tension edge of the web of the 12-in. beam to the flange of the transverse 18-in. girder. The butt weld connecting the tension flange of one of the 12-in. beams to the 18-in. girder failed at a load of 106,000 lb. corresponding to a maximum flange stress of 51,000 lb. per sq. in.

plates developed the full strength of the 12-in. beams. Only one weld failed and that was a $^1/_4$-in. fillet connecting a $^1/_2$-in. plate to the flange of a beam. Of the four specimens that had no tension plates only one, B82, developed the full flexural strength of the beams without breaking any welds. The specimen B81 developed the strength of the beam but also failed in the weld. Although A82 failed in the weld without buckling the compression flange of the beam, the unit flexural stress developed, 51,000 lb. per sq. in., is as great as flexural members in general may be expected to develop. Only one specimen, A81, made a distinctly poor showing. It developed a unit flange stress of 39,400 lb. per sq. in. The tension connection for this specimen consisted only of a butt weld between the flanges of the beam and girder, and this weld was made from the top side only and the penetration was very poor.

The results of the tests appear to indicate that a connection with a tension plate, Fig. 1*b*, will develop the full flexural strength of the beam, but this type of connection is more expensive than one without tension

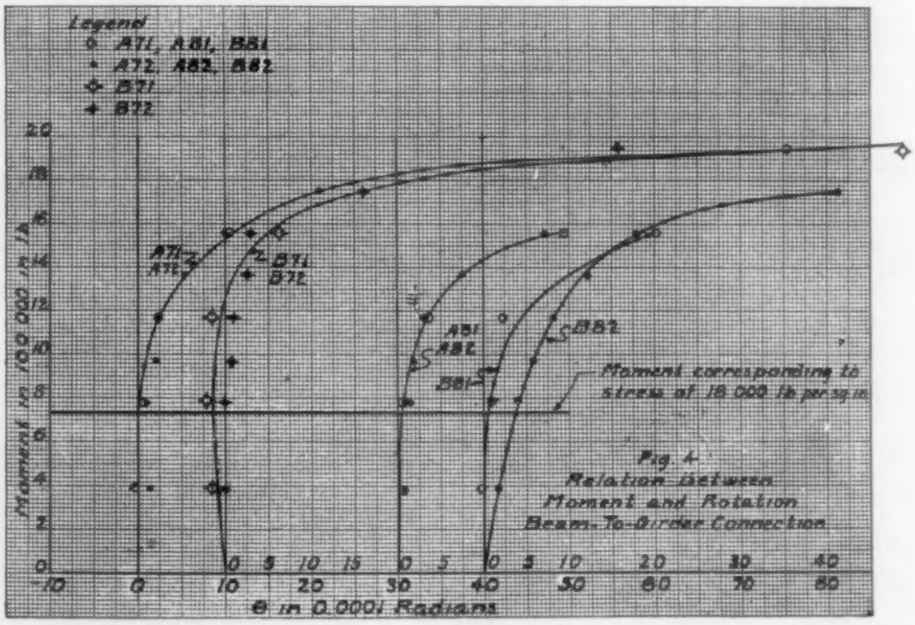


Fig. 4. Relation between Moment and Rotation Beam-To-Girder Connection

Specimen B81 was welded the same as A81 but the penetration was much better and a coated electrode was used. The butt weld connecting the tension flange of one 12-in. beam to the flange of the girder failed at a load of 102,200 lb., but the compression flange of the 12-in. beam also buckled, showing that the specimen had developed the full flexural strength of the beam. The computed maximum flange stress corresponding to the maximum load is 49,000 lb. per sq. in.

Specimen B82, in addition to the welds common to all of the A8 and B8 specimens and described in a previous paragraph, had the coped tension edge of the web of the 12-in. beam welded to the flange of the girder and the connection between the tension flange of the 12-in. beam and the flange of the girder was welded from both the top and the bottom. The compression flange buckled at a load of 115,700 lb. and none of the welds showed any signs of failure. The computed maximum unit flange stress corresponding to the maximum load is 55,000 lb. per sq. in.

In studying the experimental data relative to the beam-to-girder connections given in Table 1, a number of results are of interest. All of the connections with tension

plates and the tension plates are objectional in a floor, projecting as they do above the plane of the top flange of the beam and girder. Inasmuch as the one specimen (B82) without a tension plate which developed the full strength of the beam was the only one in which all surfaces available were utilized in welding, it seemed desirable to test more connections of this type. Accordingly four specimens M11, M12, M13 and M14 were made similar to B82 for which the tension flange of the 12-in. beam was welded from both above and below and the top coped edge of the web of the 12-in. beam was welded to the flange of the 18-in. girder. All cutting for these beams was done with a torch and the tension flange was scarfed, also with a torch, to facilitate the welding. The report of these tests, given in Table 1, shows that all specimens of the M series developed the full strength of a beam continuous over the center. Although specimen M13 developed the flexural strength of the beam, one weld failed after the flange of the beam buckled.

In the comparison of the action of the specimens reported in Table 1 with a simple beam continuous over the center, the comparison has been made on the basis of computed values for the continuous beam. As a check

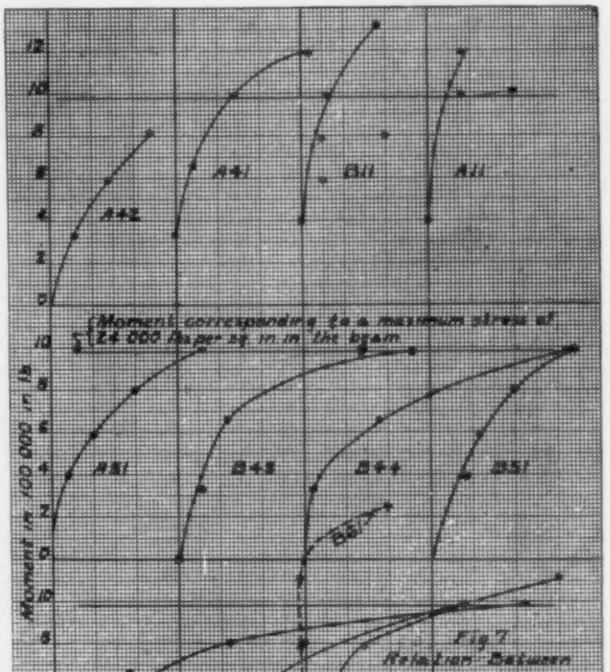
Fig. 5—Beam-to-Girder Specimen after Failure

upon this comparison, tests were made on two specimens each composed of a single beam continuous over the center. The results of these tests are reported at the bottom of Table 1.

The rigidity of the welded joint connecting beams to a girder is of interest because of its influence upon the distribution of the moment in the beam. If the ends of a uniformly loaded beam are fixed, the moment is $^1/_{12}$ WL at the ends and $^1/_{24}$ WL at the middle. A slight rotation at the ends will reduce the end moment and increase the center moment, but the carrying capacity of the beam will not be reduced by this rotation unless it is great enough to make the moment at the center of the span greater than $^1/_{12}$ WL, the moment at the end of a beam with fixed ends. This critical value of θ will be different for different spans and for different systems of loading but, except for extremely short beams and for loads concentrated at or near the center of the span, the rotation that will cause the moment at the center of a beam to exceed the moment at the ends of a similar fixed-end beam is much greater than the slight rotation between the beams and girder noted in these tests.

It should be noted that each of the beam-to-girder specimens consists of two welded joints and that the failure of either of these joints terminates the test. There were five of the beam-to-girder specimens without tension plates for which the flanges were welded from both top and bottom and the coped tension edge of the web of the beam was welded to the flange of the girder. And all five specimens, a total of ten joints, developed the full strength of the beam, although for one joint the weld failed after the flange of the beam buckled. For the specimens without tension plates that failed to develop the flange of the beam, the welds connecting the flange of the beam to the flange of the girder were welded from the top only. There were four of the beam-to-girder specimens with tension plates, a total of eight connections. All eight of these connections developed the full strength of the beam but for one the weld broke after the flange buckled. The weld that broke was a $^1/_4$-in. fillet weld connecting the $^1/_2$-in. tension plate to the flange.

3. *Girder-to-Column Connections.*—The type of specimen used in the tests of girder-to-column connections is shown in Fig. 6. Two short 12-in. 32-lb. I beams are welded to a 12-in. H column. The specimen is loaded by attaching the upper beam to the upper head of a testing machine at M and attaching the lower head at N. The left-hand end of the specimen is supported by means of a cable and counterweight as shown in the figure. Each specimen consists of two connections symmetrically located with respect to a horizontal centerline. Loads at M and N produce equal moments on the two connections. The deflection of the horizontal beams relative to bars, one on the near and the other on the far side of the specimen, bolted to the specimen at the intersection of the centerlines of the column and beam, was measured with Ames dials as indicated in the figure.



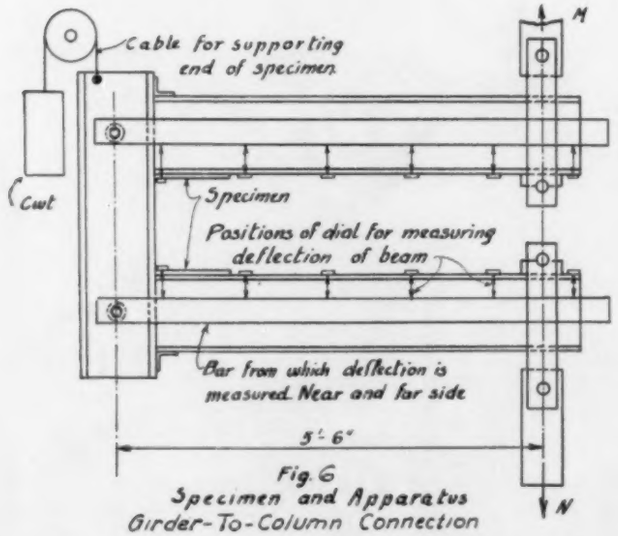


Fig. 6
Specimen and Apparatus
Girder-To-Column Connection

Rectangular building frames are usually analyzed on the basis of two assumptions: (1) Each of the two members that intersect retains its independent prismatic form up to its intersection with the axis of the other member. (2) The connections are rigid. The load at M and N that would produce a unit flexural stress of 24,000 lb.[1] per sq. in. at the intersection of the axis of the

[1] A unit stress of 24,000 lb. per sq. in. is allowed in some specifications for a stress due to a wind load combined with dead or live load, providing the structure is suitably proportional to resist the dead and live load at the usual working stresses.

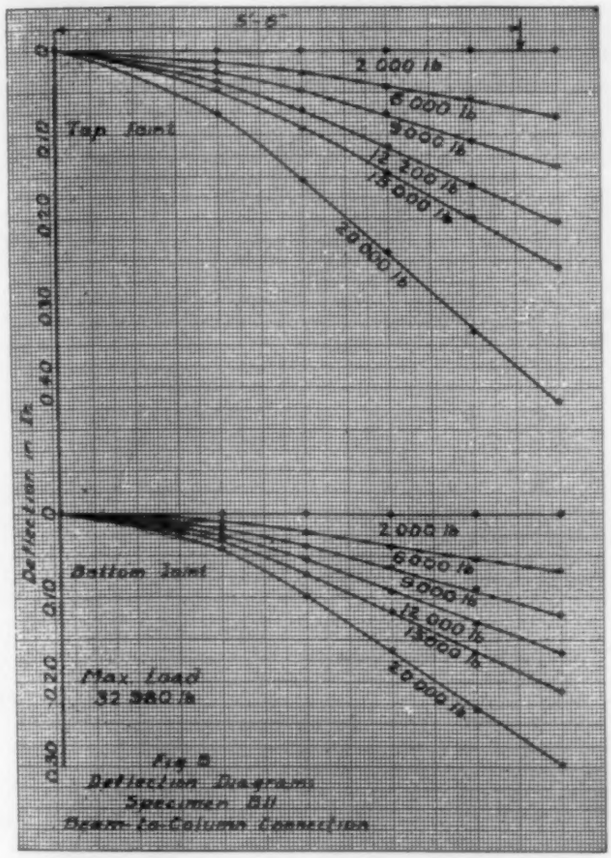


Fig. 8
Deflection Diagrams
Specimen B11
Beam-to-Column Connection

column and the beam, if the latter were extended, is 14,800 lb. This will be used in the following discussion as the design load for the specimen.

If the deflection of the girder exceeds the deflection computed on the basis of the two assumptions stated above, the difference is attributed to the lack of rigidity of the connection. Quantitatively, the rotation due to a lack of rigidity is the quotient obtained by dividing the difference between the two values for the deflection at a given load (one measured and the other computed) by the length of the beam. The length of beam used in these computations is the distance from the axis of the column to the line of action of the force, *M N*.

The details of the individual specimens and the results of the tests are given in Table 2. The relation between the moment and the rotation is given in Fig. 7 and a typical deflection diagram is given in Fig. 8. Figure 9 shows a specimen after failure.

Specimens of the A4 and B4 type appear to be the strongest and all of them developed the full strength of the beams. Specimens A5 and B5, which are similar to A4 and B4 except that the beam is not welded directly to the column, were not as strong as the A4 and B4. The stiffness of all connections is worthy of note.

Each of the A4 and B4 type of specimens contained two connections so that the four specimens really represent eight connections, and all of them developed the full strength of the beam in flexure and none of the welds showed any indication of failure.

The results obtained from the tests of A6 are worthy of special study. The connections for this specimen are similar to the connections for A4 except that for the latter the beam is connected to the flange whereas for the former it is connected to the web of the column. Because of the flexibility of the web of the column in the direction of stress from the beam, the central portion of the web is not able to carry its share of the stress and there is a stress concentration in the column near the junction of the web and the flange. This is indicated in Fig. 10 in which the arrows indicate holes in the web. Specimen B9, for which the beam also connects to the web of the column, has a horizontal shear plate *S* welded to the tension flange of the beam and to the flanges of the column so that the stress can go directly into the flanges without going through the web of the column.

Further details of the tests may be obtained from Table 2.

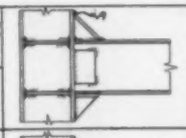
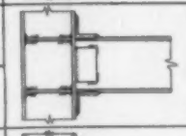
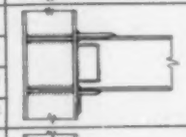
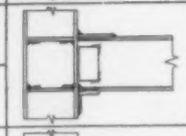
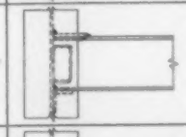
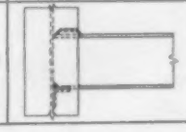
Reversed-Load Tests

4. *Girder-to-Column Connections.*—If the girder-to-column connections of a building frame are stiff, any swaying of the frame due to wind[3] will produce a moment on the joint. Moreover, if the joint is stiff, gravity loads on the girders will also produce a moment. Gravity-load moments on a joint may vary in magnitude but seldom change in sign, whereas wind moments not only vary in magnitude but may be subjected to a complete reversal. It seemed desirable, therefore, to supplement the static tests with reversed-load tests.

The problem is not strictly a problem in the fatigue strength of metal, and for two reasons. (1) In a fatigue study the problem is to determine the unit endurance limit of the material. In the study of moment-resisting connections the problem is to devise a connection between two members whose design has already been determined. That is, the problem is not so much determining the unit strength of the connection as it is devis-

[3] This and subsequent statements relative to wind forces also apply to earthquake forces.

TABLE 2
RESULTS OF STATIC TESTS
GIRDER-TO-COLUMN CONNECTIONS

SPECIMEN		MAXIMUM FLANGE STRESS	TYPE OF FAILURE
A11		28 900	WELD FAILED
B11		48 600	FLANGE BUCKLED
A31		28 310	WELD FAILED
B31		31 300	WELD FAILED
A41		48 600	FLANGE BUCKLED
A42		46 000	FLANGE BUCKLED
B43		46 400	FLANGE BUCKLED
B44		46 100	FLANGE BUCKLED
A51		35 900	WELD FAILED
B51		44 800	FLANGE BUCKLED WELD FAILED
A61		34 200	FLANGE BUCKLED WELD FAILED
B61		38 100	FLANGE BUCKLED

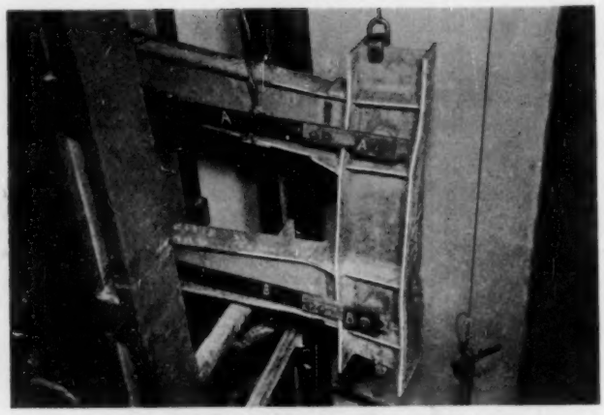


Fig. 9—Girder-to-Column Specimen after Failure

ing a connection that will develop the members. (2) In a fatigue study the number of stress cycles is of the order of 100,000,000. Although the joint in the wind bracing of a building frame is subjected to reversed moments, the probable number of stress cycles during the life of the building is small. The author in planning the tests has attacked the problem from the following view-point.

The beams and girders forming a frame have been selected on the basis of the stress cycle to which they may be subjected. A certain type of joint is proposed for connecting these members. The information desired is made up of two parts. (1) What is the probable maximum number of stress cycles likely to occur in the life of the structure? (2) How many stress cycles will the joint withstand before failure? The latter, obviously, should be many—ten to twenty times the former.

The stress cycle for a joint in the wind bracing of the steel frame of a building depends upon the relation of the wind load to the gravity load on the girders. If the latter is zero, the stress cycle may be a complete reversal. If the maximum moments on the connections due to wind and to gravity are equal in magnitude, the stress cycle will vary from zero to a maximum, and the latter will equal the arithmetic sum of the two parts. Since the gravity moment, which is not reversible, produces tension at the top of the connection, the stress on the top of the connection will vary from a maximum tension to a lesser tension, from a maximum tension to a zero stress, or from a maximum tension to a compression lesser in magnitude than the tension, depending upon the relation of the gravity moment to the wind moment. And the stress cycle for the bottom of the connection will vary from a maximum compression to a lesser compression, from a maximum compression to a zero stress or from a maximum compression to a tension lesser in magnitude than the compression.

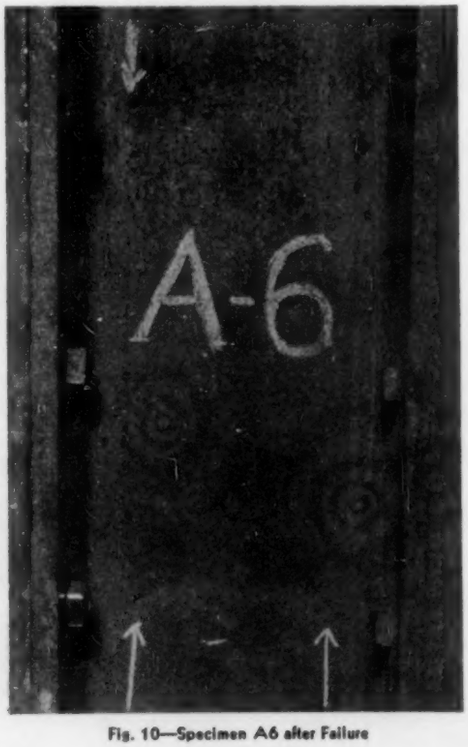


Fig. 10—Specimen A6 after Failure

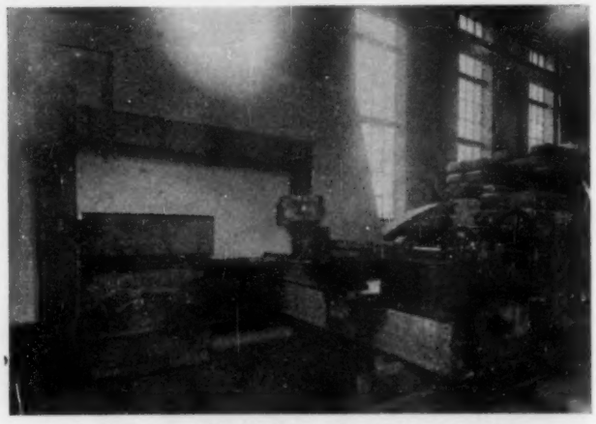


Fig. 11—Reversed-Load Test of Girder-to-Column Connection

In the steel frame of a building, the girders of the wind bracing usually carry considerable load and in relatively few instances is the joint in the wind bracing subjected to a complete reversal of stress. In the upper stories of a frame the wind moment is small and a not uncommon condition is one in which the wind moment does not exceed in magnitude the moment due to gravity load. Under these conditions the moment on the connection is repeated but not reversed. In the lower stories of the frame the wind moment is large and a not uncommon condition is one in which the wind moment is much greater than the gravity-load moment. If the latter is one-third the former then the connection may be subjected to a resultant moment twice as great in one direction as the other; and the maximum stress is tension at the top and compression at the bottom of the connection. Most of the connections were tested under a load cycle for which the stress at the top varied from a tension of 24,000 lb. per sq. in. to a compression of 12,000 lb. per sq. in. These stresses are the computed values at the face of the column based upon the forces on the dynamometer and the full section of the I beam. For two specimens the stress at the top varied from a tension of 24,000 lb. per sq. in. to zero.

Figure 11 shows a specimen in the testing machine. It consists of a 12-in. I beam welded to a 12-in. H column. The column is bolted to the bed of the machine and the outer end of the beam is connected to a motor-driven variable-throw eccentric through a dynamometer. The dynamometer, an open rectangular steel frame, is shown in the figure but the eccentric is hidden by the large bearing of the main shaft. The Ames dial of the dynamometer indicates the vertical force being transmitted to the end of the beam. The throw of the eccentric was adjusted until the desired force for a given test had been obtained. The machine operated at a

speed of 33 stress cycles per minute. The procedure was to adjust the machine to the desired stress cycle for a given specimen and then run the test until a crack appeared in the specimen. The machine was stopped occasionally to check the stress cycle and make readjustments if necessary. The joint was whitewashed to facilitate the detection of cracks.

Sixteen specimens were tested and the results of the tests are presented in Table 3. The first column gives the details of the connections. A coated electrode, the same one for all specimens, was used for all welds. A lack of care in the adjustment of the eccentric caused the stress limits to vary from the values desired for some tests.

Specimens of the A1 series had small brackets at the connection. Specimen A1-1 withstood 50,000 repetitions of the stress cycle ranging from a tension at the top of 25,600 lb. per sq. in. to a compression of 10,800 lb. per sq. in. The range of the stress cycle was then increased from a tension of 37,000 lb. per sq. in. to a compression of 17,200 lb. per sq. in. Cracks were detected at A and B after 700 repetitions of the latter stress cycle. Specimen A1-2 had a noticeable undercut at B and a crack in the flange of the beam was detected at this point after 35,380 repetitions of the stress cycles. Specimens A1-3 and A1-4 both failed by cracks developing in the flange at the edge of the weld.

Specimens of the A2 series were without brackets at the connection. A shelf angle was shop-welded to the column and the lower flange of the beam was welded to the shelf angle. For this latter connection a $^1/_2$-in. flat fillet weld was used along the edge of the flange on top of the angle and a $^1/_2$-in. overhead fillet weld was used across the bottom of the flange along the edge of the angle. The top flange of the beam was connected to the flange of the column with a $^3/_4$-in. fillet weld on the top of the beam. There were no shear plates used to connect the web of the beam to the flange of the column, instead the web was welded direct to the column with a fillet weld on each side. In addition to the above, specimen A2-1 also had a fillet weld on the under side of the top flange and on the top side of the bottom flange of the beam. Nevertheless specimen A2-2 withstood a greater number of stress cycles than A2-1. Both specimens were undercut at B and failure began in the flange of the beam at the undercut just outside of the weld.

Specimens of the A3 series had an angle similar to a shelf angle at both the top and the bottom of the beam connected much the same as the single shelf angle of the A2 series described in the preceding paragraph. For A3-2 the only flange connection between the beam and column was through the angles, but there were welds connecting the flanges of the beam of A3-1 directly to the column, a $^1/_2$-in. fillet weld under the top flange and a similar weld on top of the bottom flange. A well-developed crack was detected at B of A3-2 after 387 cycles, failure being due to ripping the upper angle from the column, beginning at the bottom end of the vertical fillet. The crack probably had formed earlier as failure was not expected so soon and the weld was not examined until a noticeable falling off in the dynamometer reading directed the operator's attention to it. The first crack was detected in A3-1, the specimen which had the flanges welded directly to the flange of the column, after 31,700 cycles. An additional 700 repetitions of the cycle caused very little enlargement of the crack or falling off of the load.

Specimens of the A4 series had a bottom shelf angle connected in the manner already described for the A2 series. The top flange of the beam was connected to the flange of the column through a plate shop-welded to the flange by means of a $^1/_2$-in. flat fillet at the end of the

TABLE 3

REVERSED-LOAD TESTS

GIRDER-TO-COLUMN CONNECTIONS

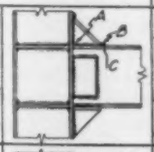
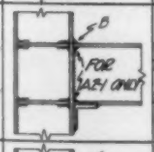
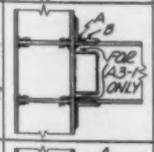
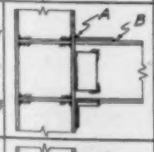
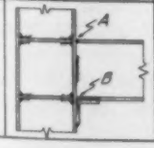
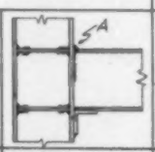
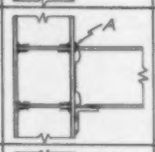
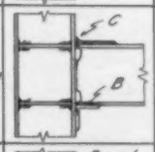
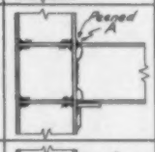
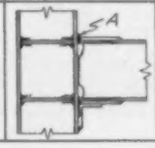
SPECIMEN		STRESS RANGE	NO. OF CYCLES	REMARKS
A1-1		25 600 T TO 10 800 C 37 000 T TO 17 200 C	50 000 700	CRACKS AT A AND B
A1-2		26 100 T TO 10 400 C	35 380	WELD UNDERCUT AT B BEAM FAILED AT C
A1-3		24 500 T TO 12 100 C	78 400	BEAM FAILED AT B
A1-4		23 900 T TO 12 300 C	57 400	BEAM FAILED AT B
A2-1		25 600 T TO 11 900 C	19 150	FLANGE UNDERCUT AT WELD FLANGE FAILED AT B
A2-2		24 000 T TO 12 750 C	43 200	FLANGE UNDERCUT AT WELD FLANGE FAILED AT B
A3-1		25 400 T TO 10 900 C	31 700	ANGLE FAILED AT A
A3-2		23 600 T TO 12 200 C	387	WELD FAILED AT B
A4-1		25 500 T TO 12 500 C	13 750	WELD FAILED AT A AND B
A4-2		23 900 T TO 13 500 C	36 000	WELD FAILED AT B
A4-3		24 000 T TO 13 888 C	19 000	WELD FAILED AT A
M1		24 000 T TO 12 000 C	13 300*	CRACKS AT A AND B
M2		24 000 T TO 12 000 C	4 150	CRACK AT A
M3		24 000 T TO 12 000 C	5 760	VERY SMALL CRACK AT A
M3a		24 000 T TO 12 000 C	7 500	SMALL CRACK AT B
		24 000 T TO 0	9 250	SMALL CRACK AT C
M4		24 000 T TO 0	23 000	SMALL CRACK AT A
M5		24 000 T TO 12 000 C	6 900	SMALL CRACK AT A

plate and across the top of the top flange and also by longitudinal overhead fillets under the plate and along the edges of the flange. The plate was field welded to the column by means of a fillet across the plate at A. Small cracks were detected in specimen A4-1 at both A and B after 13,750 repetitions of the stress cycle. The crack at A developed rapidly with a few additional repetitions of the stress cycle. A small crack was detected in specimen A4-2 at B after 36,000 cycles and another one at A after 36,700. The cracks had developed so as to cause a falling of 10 per cent in the maximum moment at a total of 41,900 cycles. For specimen A4-3 a fine crack was detected at A after 19,000 stress cycles. This crack developed so as to cause a falling off of 10 per cent in the maximum moment at a total of 22,000 cycles.

All of the specimens of the A series described in the preceding paragraphs were welded in the factory of the Hollup Corporation by an expert welder in their employ. The specimens of the M series which are described in the following paragraphs were welded by Mathew Scioletich[4] in the Materials Testing Laboratory of the University. It was hoped that by having the welding directly under the control of the investigators it would be possible to determine the effect of minor variations in the details of the specimen.

Specimen M1 was similar to specimens A2-1 and A2-2 but differed in these respects. The fillets connecting the web of the beam to the girder were only 6 in. long and they were very much lighter than the corresponding fillets of the A2 series. The shelf was planned as an erection shelf and its connection with the bottom flange of the beam was very light. The space between the end of the bottom flange of the beam and the column was about $^1/_4$-in. wide when welding began and the connection was made with a butt joint, the metal for the finished weld being only slightly above the flange of the beam. The top flange of the beam was scarfed and the connection was made with a butt weld with the weld metal projecting only slightly above the top of the top flange. After the weld had been completed from the top a small overhead bead was laid on the bottom of the flange. A small crack was detected at B on the bottom flange after 4400 cycles and another was detected at A on the top flange after 13,300 cycles. The cracks increased in size very slowly and there had been practically no falling off of the load at 19,100 cycles. But beginning at this time the crack spread rapidly and the load had fallen off 20 per cent at 20,300 cycles.

This specimen was welded in the testing machine with the outer end of the beam restrained against vertical motion by the connection to the eccentric. Since this connection was through the dynamometer, a ready means was available for measuring the moment on the joint as welding proceeded. Welding began at the bottom and proceeded as follows: (1) Connection to shelf angle. (2) Web of beam to column. (3) Upper flange of beam to column. The welding stresses in the beam at the face of the column, computed on the basis of the dynamometer reading and the full section of the beam, were as follows, the stress being tension at the top and compression at the bottom in all instances. After the bottom flange and web had been welded and before the welds had cooled, 3400 lb. per sq. in.; after the top flange had been welded and before the weld had cooled, 6100 lb. per sq. in.; and after the weld had all cooled, 6400 lb. per sq. in. As stated above, these stresses have been computed from the section modulus of the beam and the moment on the section at the face of the column. Any local temperature stresses, and they might be large, would not be detected by these computations.

Specimen M2 was similar to M1 but differed in the following details. The top and bottom flanges were both scarfed. The shear weld extended over the upper half instead of over the middle half of the web. The weld in the top flange, in addition to filling the scarf, was piled up so that it looked like a $^1/_2$-in. fillet weld across the top flange of the beam.

The order of welding for this specimen was from the bottom up, the same as for M1, and the computed temperature flexural stress in the beam at the face of column A after the welds had cooled, based upon the dynamometer readings, was 4200 lb. per sq. in.

A small crack was detected in the top flange after 4150 cycles and a large crack was detected in the top flange after 7100 cycles.

Both flanges of M3 were scarfed and the bottom flange was welded to the shelf angle with a $^1/_2$-in. fillet weld 4 in. long on each edge. The web was cut away at the top and bottom so that the bead on the underside of the top flange and on the top side of the lower flange would be continuous. The top of the upper bead on the top flange extended above the top of the flange and gave the appearance of a $^1/_2$-in. fillet weld.

A very small crack was detected in the weld at A after 5760 cycles. The test was stopped and the weld metal was chipped off flush with the top of the top flange and a plate added to form specimen M3a. The plate was scarfed and the butt weld connecting it to the plate was built up above the top of the plate adjacent to the face of the column, giving the appearance of a $^1/_2$-in. fillet weld. A small crack developed in the bottom flange at B after specimen M3a had been subjected to 7500 cycles. As the connection of the top flange was still intact the minimum stress of the stress cycle for the top flange was changed from 12,000 lb. per sq. in. compression to zero and the test continued. A fine crack developed in the top flange at C after specimen M3a had withstood 9250 cycles. As this crack did not cause an appreciable falling off in the load the test was continued. After 43,500 stress cycles there had been no appreciable falling off in the load and the machine was allowed to run without an attendant until at the end of 65,000 cycles the connection between the beam and column had been almost completely severed. Rapid failure began somewhere between 43,500 and 65,000 cycles.

Provision was made in the tests of M3 to measure the movement of the flanges of the beam relative to the flanges of the column as follows: A small angle was welded to each flange of the beam $7^7/_8$ in. from the face of the column and a gage hole was drilled in each angle just outside of the edges of the flange. This hole was $^1/_{16}$ in. above the top flange for the top angle and $^1/_{16}$ in. below the flange for the bottom flange. Corresponding holes were drilled in the face of the column. Variations during a cycle of the distance from a hole in an angle to the face of the column were measured with an attached Ames dial.

At the beginning of the test of M3 the variation in this gage length was 0.0083 in. for the top flange and 0.0079 in. for the bottom flange. As the stress range was 36,000 lb. per sq. in. the measured deformation is just slightly less than the elastic deformation. The fact that the deformation was slightly less for the bottom flange than for the top is probably due to the fact that some of the stress in the lower flange was taken by the horizontal leg of the shelf angle. The deformation in the top flange after 5760 cycles, when the crack at A was

[4] A graduate student in Civil Engineering who assisted the author in this investigation. Mr. Scioletich had had three months' experience as a structural welder and had a rating as a Class B welder.

detected, had increased from 0.0083 in. to 0.0092 in. and the deformation in the bottom flange increased from 0.0079 to 0 0080 in., the latter change being smaller than the tolerance of the instrument. The crack was at the midwidth of the flange just over the web and did not extend to the edge of the flange in either direction.

The deformation of specimen M3a at the beginning of the test was 0.0065 in. for the top flange and 0.0078 for the bottom flange. The decrease in the deformation of the top flange of M3a relative to that for M3, was due to the addition of the plate which reduced the unit stress in the flange of the I beam over a part of the gage length. After M3a had been subjected to 7500 stress cycles, at the time the crack was detected in the bottom flange at C, the deformation was 0.0067 in. and 0.0090 in. for the top and bottom flanges, respectively. When the minimum stress of the stress cycle was changed to zero, these deformations became 0.0050 in. and 0.0063 in., respectively. A set of readings was taken after 14,760 cycles, 5510 cycles after the crack in the top flange was detected. These readings gave a deformation of 0.005 and 0.0062 in., the same as the values observed when the stress cycle was first changed. After an additional 13,700 cycles the deformations were 0.0054 in. and 0.0062 in., and after a further addition of 2400 more cycles the values were 0.0053 in. and 0.0063 in. That is, 21,610 stress cycles occurring after a crack had been detected in each of the two welds, one for the top and the other for the bottom flange, produced no appreciable increase in the deformations.

Both flanges of the beam for specimen M4 were scarfed and the web was cut back from the flange to enable the welder to lay a continuous bead on the top side of the bottom flange and the bottom side of the top flange. The weld on the top of the top flange was flush with the top of the beams but curved upward at the face of the column to form a concave fillet having a radius of about $^1/_4$ in. This weld was peened with an air hammer and the finished surface was smooth. The stress cycle for the entire test ranged from 24,000 lb. per sq. in. tension on the top flange to zero.

A very small crack was detected in the top flange at A after 23,000 cycles. This crack was at midwidth of the flange and was only about $^1/_2$ in. long when first discovered. The test was continued and at 28,800 cycles the crack had grown, increasing in both length and width, but did not extend to either edge of the flange. From this point on there was some falling off on the load but at 30,400 cycles the crack had not extended to either edge of the flange. At 31,800 cycles the top flange of the beam was completely severed from the column and the web was cracked, beginning in the weld at B and extending into the web for a distance of 6 in.

The deformation of the flanges from a point 8.1 in. from the face of the column to the base of the column was measured in the same manner as for specimen M3. This deformation at the beginning of the test was 0.0064 in. and 0.0066 in., for the top and bottom flanges, respectively. Although a fine crack was detected at 23,000 cycles, there was no increase in the deformation until later.

The M5 specimen had a plate shop welded to both the top and bottom flanges of the beam. The top flange and both plates were scarfed and the web was cut away from both the top and the bottom flanges so as to enable the welder to lay a continuous bead on the inside of the flanges. The bottom flange was not welded to the shelf angle but was connected to the column with butt welds as shown in the sketch. A small crack was detected at the midwidth of the top flange at A at 6900 cycles and this crack had increased in size so as to cause a falling off of the load at 7500 cycles. The bottom flange cracked outside of the weld at 13,000 cycles.

5. *Discussion of the Results.*—These tests were intended as a reconnaissance to develop the feasibility of welding the steel frame of a building for complete continuity and to obtain information on which to base a more comprehensive investigation if welding for complete continuity appeared feasible. The investigation was not sufficiently comprehensive to justify design specifications, but the results appear sufficiently consistent to appear to justify some tentative conclusions along certain lines, subject, however, to further verification. These tentative conclusions are as follows:

1. Beam-to-girder connections having a tie plate on the tension flange of the beam have sufficient strength when subjected to static loads to develop the flexural strength of the beam and sufficient stiffness to justify designing the beam on the basis of fixed ends. Beam-to-girder connections without tie plates are somewhat inferior to those with tie plates, nevertheless the ten connections of this type for which the tension flange was welded from both the top and bottom and for which the coped tension edge of the web was welded directly to the flange of the girder (Specimens B82 and M11, M12, M13 and M14 of Table 1) all developed the full strength of the beam, but for one connection, M13, the weld also broke after the flange buckled.

2. Of the girder-to-column connections subjected to static tests, the eight of the A4 and B4 type all developed the full flexural strength of the beam and no welds failed. The B11 connections developed the full flexural strength of the beam but the similar connection, A11, failed in the weld at a comparatively small load. The fracture of the latter showed a very poor penetration at A, Table 2. The diagrams of Fig. 7 show that all of the connections with a possible exception of A11 and B11 were seriously lacking in stiffness. The reason for this is apparent in Fig. 9. Because brackets were not used except for A11 and B11, the shearing stress in the web of the column was excessive and the rotation between the column and girder was due largely to the shear detrusion in the web of the column rather than because of the deformation in the weld. It would appear therefore that either a bracket should be used or the web of the column should be reinforced so as to reduce the intensity of the shearing stress. In other words, it would appear that further consideration should be given to the design of welded connections of this type.

3. The results of the girder-to-column connections when subjected to the reversed load tests are given in Table 3. The adequacy of the various designs is a matter of personal opinion. The connections were subjected to the design stress (for wind bracing) and the test consisted of determining the number of stress cycles required to produce failure. The question on which structural engineers differ is the number of stress cycles that the connection must withstand to be acceptable.

Very few tornadoes occur at any one site during the life of a building and a connection in a building frame will not be subjected to many cycles involving maximum design stress during one tornado. For these reasons it is improbable that any connection in a building frame will be subjected to more than a few hundred cycles involving maximum design stress during the life of a building.

Types of construction which are commonly used in building frames designed for continuity, monolithic reinforced concrete and structural steel fabricated with rivets, have not been subjected to reversed-load tests similar to the tests described for the welded connections,

and it is not possible to compare the performance of welded connections with either of these types of accepted construction.

A number of structural engineers have witnessed the tests described in this paper and the author has invariably asked them what they consider to be a reasonable expectancy for the joints. As might be expected, the answers have covered a wide range—actually from 1000 to 1,000,000 stress cycles.

The author believes that a connection which will withstand 10,000 stress cycles of the range used in these tests, 24,000 lb. per sq. in. tension to 12,000 lb. per sq. in. compression in the top flange, is acceptable for wind and earthquake bracing in the steel frame of a building. On this basis, a number of the connections tested would appear acceptable.

6. *Acknowledgments.*—This investigation is a part of the work of the Engineering Experiment Station of the University of Illinois, of which Dean M. L. Enger is the Director, and the Department of Civil Engineering, of which Professor W. C. Huntington is the Head. The steel was furnished by the Illinois Steel Company and prepared for welding by the Chicago Bridge and Iron Works. The tests were made by Mathew Scioletich, a graduate student in Civil Engineering, working under the supervision of the author. All of the specimens except those of the M Series were welded by the Hollup Corporation; the specimens of the M Series were welded in the laboratory by Mathew Scioletich, using equipment furnished by the General Electric Company. The money to pay the direct expenses of the tests was provided by the Hollup Corporation.

CURRENT WELDING LITERATURE

Airplane Manufacture. Weldability of High-Tensile Steels from Experience in Airplane Construction, with Special Reference to Welding Crack Susceptibility, J. Mueller. Nat. Advisory Committee Aeronautics—Tech. Memo. no. 779 (Nov. 1935), 25 pp., 2 supp. sheets.

Automobile Manufacture. Welding Ford Automobiles. Heat Treating & Forging (Sept. 1935), vol. 21, no. 9, pp. 440–441. Enumeration of welds required for Ford V-8; body welding; welding strip.

Automobile Manufacture. Welding Machines for Assembling Automobile Parts, C. M. Taylor. Machy. (N. Y.), vol. 42, no. 3 (Nov. 1935), pp. 175–176.

Automotive Engines. New Method of Reconditioning Engine Parts, R. Leonhardt. Indian Eng. (June 30, 1934), vol. 95, no. 26, pp. 510–511.

Bridges, Steel. Billingham Branch Bridge, W. P. Haldane and G. Roberts. Instn. Civ. Engrs.—Min. Proc., vol. 240, no. 5017, pt. 2, 1935, 32 pp., 1 supp. plate. Design and construction of welded plate-girder highway bridge consisting of 5 spans, 28 to 64 ft. in length; details of welding operations and tests.

Bridges, Steel. Welded Bridge and Structural Work, A. Doernen. Welding J. (Oct. 1935), vol. 32, no. 385, pp. 304–305. Progress of welding in structural work and its advantages from point of view of construction, economy and aesthetics.

Chains. Electric Welding of Chain by Low Voltage Process, T. F. Holden. Welding J. (Sept. 1935), vol. 32, no. 384, pp. 270–272.

Coal Mines and Mining. Oxyacetylene Welding and Cutting in Coal Seams, E. S. Wade. W. Va. Coal Min. Inst. Proc., 26th annual mtg. Dec. 5–6 1935, pp. 97–105.

Concrete Slabs Reinforced with Welding Wire Fabric, Tested at University of Delaware under Direction of T. D. Mylrea, April 25, 1935. Illus., diagrs., charts, paper, apply to University of Delaware, Newark, Del.

Dies. Hard-Surfacing Dies and Punches, J. B. Ames. Welding Engr. (Oct. 1935), vol. 20, no. 10, pp. 19–20.

Electric Welding, Resistance. What Is Shot-Welding? C. O. Herb. Machy. (N. Y.), vol. 42, no. 2 (Oct. 1935), pp. 97–100.

Electric Welding Machines. New High Frequency Arc Welding Set. Engineer (Nov. 22, 1935), vol. 160, no. 4167, pp. 548–549.

Electrodes. Manufacture of Welding Electrodes, C. H. Davy. Mech. World (Nov. 15, 1935), vol. 98, no. 2550, pp. 472 and 474.

Exhibitions. Shipping, Engineering and Machinery Exhibition. Welding J. (Sept. 1935), vol. 32, no. 384, pp. 262–263. Welding and cutting exhibits as seen at Olympia, London; general illustrated description of exhibits.

Gas Pipe Lines. Service Connections to Cast-Iron Pipe, H. S. Harris. Pac. Coast Gas Assn.—Proc., vol. 25, 1934, pp. 75–83.

Locomotive Boilers. Application to Locomotive Boilers and Tenders of Fusion Welding, I. J. Pool, L. C. Ruber and H. H. Service. Boiler Maker & Plate Fabricator (Oct. 1935), vol. 35, no. 10, pp. 276–277; (discussion) 279–280 and 286.

Locomotive Boilers. Recommendations for Application to Locomotive Boilers and Tenders of Fusion Welding, H. H. Service, T. M. Stewart, M. A. Thompson, J. J. Davey and F. C. Hasse. Boiler Maker & Plate Fabricator (Oct. 1935), vol. 35, no. 10, pp. 277–279; (discussion) 279–280 and 286.

Metals. Hard-Facing Materials and Methods, R. E. Brown. Metal Progress (Oct. 1935), vol. 28, no. 4, pp. 136–140 and 144.

Metals. Seizure of Metals at Elevated Temperatures and Methods of Testing for Propensity Toward Seizure, J. W. Bolton. Am. Soc. Mech. Engrs.—Progress Report (Dec. 1935), 9 pp.

Oxyacetylene Welding Torches. Torch Aids Diemaker, K. Janizewski. Am. Mach. (Nov. 6, 1935), vol. 79, no. 23, pp. 825–827.

Penstocks. All-Welded Penstock for Norris Dam. Boiler Maker & Plate Fabricator (Nov. 1935), vol. 35, no. 11, pp. 323–324.

Pipe Lines. All-Welded Irrigation Pipe. Welding Engr. (Oct. 1935), vol. 20, no. 10, pp. 32–33.

Railroad Civil Engineering. Bridge and Building Officers Discuss Problems of Day. Ry. Eng. & Maintenance (Nov. 1935), vol. 31, no. 11, pp. 660–692.

Railroad Maintenance of Way. Report of Committee XXVII—Maintenance of Way Work Equipment. Am. Ry. Eng. Assn.—Proc., vol. 36, 1935, pp. 267-301; (discussion) 954–956.

Railroad Tracks. Report of Special Committee on Complete Roadway and Track Structure. Am. Ry. Eng. Assn.—Proc., vol. 36, 1935, p. 117; (discussion) 957.

Railroad Tracks. Supplemental Report of Committee V—Track. Am. Ry. Eng. Assn.— Proc., vol. 36, 1935, pp. 911–915.

Rails. Report of Special Committee on Stresses in Railroad Track. Am. Ry. Eng. Assn.—Proc., vol. 36, 1935, p. 243; (discussion) 957–958.

Rails. Frisco Combines Joint-Bar with Rail-End Welding. Ry. Eng. & Maintenance (Nov. 1935), vol. 31, no. 11, pp. 956–959.

Rudders. All-Welded Stream-Lined Rudder. Shipbldr. & Mar. Engine-Bldr., vol. 42, no. 310, p. 633.

Shipbuilding by Welding, N. M. Hunter and H. W. Townsend. North-East Coast Instn. Engrs. & Shipbldrs.—Advance Paper mtg. Nov. 15, 1935 14 pp. See also Shipbldg. & Shipg. Rec. (Dec. 5, 1935), vol. 46, no. 23, pp. 636–638.

Stadiums. Bessemer High School Stadium, W. N. Woodbury. Civ. Eng. (N. Y.), vol. 5, no. 12 (Dec. 1935), pp. 796–797.

Stainless Steel. Notes on Welding Important Groups of Stainless Steel, E. E. Thum. Metal Progress (Oct. 1935), vol. 28, no. 4, pp. 111–116.

Steam Pipe Lines. Steam Mains for Modern Plants, A. G. Bugden. Iron & Coal Trades Rev. (Nov. 15, 1935), vol. 133, no. 3533, p. 811.

Steam Pipe Lines. Welding High Pressure Steam Piping at U. S. Industrial Alcohol Co. Plant, J. A. Freiday. Heating, Piping & Air Conditioning (Dec. 1935), vol. 7, no. 12, pp. 568–569.

Structural Steel. Controlling Welding in Structural Steel Fabricating Shop, R. E. Kinkead. Welding Engr. (Oct. 1935), vol. 20, no. 10, pp. 24–25.

Welding. Modern Methods of Welding, C. H. Davy. Welding J. (Oct. 1935), vol. 32, no. 385, pp. 298–300 and 309–310; (discussion) 310.

Welding. Some Comments on Welding Procedure, H. N. Wallin. Welding Engr. (Oct. 1935), vol. 20, no. 10, pp. 29–31.

Welds. Some Notes on Preheating and Contraction and Expansion, F. E. Totten. Welding Engr. (Oct. 1935), vol. 20, no. 10, pp. 22–23.

Welds. Inexpensive Weld Tests, R. B. Lincoln. Welding Engr. (Oct. 1935), vol. 20, no. 10, pp. 26-28.

Welds. Testing Welded Joints, H. J. Gough and W. J. Clenshaw. Mech. World (Nov. 15, 1935), vol. 98, no. 2550, pp. 478–479.

WELDING SOCIETY ACTIVITIES AND RELATED EVENTS

Welding Research Committee—Engineering Foundation

Requests for aid to several small researches, and information of numerous others but loosely related, and many needing assistance, have prompted the Engineering Foundation to make an appropriation for initiating a coordinated comprehensive research in all phases of welding. Welding is today the most important and widely employed tool in industry and in nearly all of its applications notable savings are effected with superior quality of product.

However, the welding problem is so complicated and the temptation to effect economies is so great that the welding of structures has sometimes been undertaken without a thorough knowledge of the problems involved. Moreover, most of the literature of importance is of very recent date, scattered throughout a wide range of publications and in many languages, and most of it is not available to those actively responsible for the planning and conduct of important welding operations.

One of the first steps in the proposed program is to make a critical review of the World's Welding Literature and present in readily useable form the best knowledge available as a result of past research and experience here and abroad. This work will be done by a committee under the auspices of Mr. J. H. Critchett. This will save time and money for the interested industrial corporations, as well as for practicing engineers and research workers.

Another step will be the coordination of numerous researches already under way in forty or more universities and the starting of new ones where needed. Under the auspices of the Foundation the Welding Research Committee will serve as a clearing-house for research information in welding by making available translations of important articles appearing in the foreign literature, and reports of investigations conducted in the universities, governmental departments and private corporations in this country. This latter work will be conducted by two committees, one on Fundamental Research under the chairmanship of Mr. H. M. Hobart, and the other on Industrial Research under the chairmanship of Colonel G. F. Jenks.

It is the intent of the latter committee to make a thorough canvass of the investigations under way, contemplated or needed by industry without interfering in any way with investigations of a confidential nature. The universities will cooperate by conducting worth while investigations as may be needed by industry (some sixty are now under way under the auspices of the Fundamental Research Committee) although specific assignment may in many cases be made to industrial and governmental laboratories.

The project is sponsored jointly by the AMERICAN WELDING SOCIETY and the American Institute of Electrical Engineers. Industry will be requested to supplement an initial contribution of $5000 made by the Engineering Foundation to launch the project by cash contributions of $10,000 per year for three years, and what is more important by whole-hearted cooperation. This will assure the continued interest and support by the Foundation and the success of the project. Funds obtained will be used in expediting progress in the digest of the world's welding literature and in supporting specific needed researches agreed upon by industry.

Translation of Important Foreign Articles Relating to Welding

The Fundamental Research Committee of the AMERICAN WELDING SOCIETY in cooperation with the Engineering Foundation Welding Research Committee is seeking to establish a procedure for making available to the research workers of this country, the knowledge and experience abroad gained as a result of expensive research work. It is rare to find instances of any adequate recognition on the part of American publishers of technical and engineering books and magazines of the importance of these activities in foreign countries. Consequently, the F.R.C. is seeking to establish a cooperative arrangement among a limited number of companies and individuals for making translations and supplying them in sufficient number so that they can become available to those who desire them.

It is planned to make the central office of the AMERICAN WELDING SOCIETY the clearing-house for this information. Although no definite plans have been worked out for making these copies available, it is suggested that any reader who believes from its title that the translation of a particular paper would be of value to him should write to Mr. W. Spraragen, Technical Secretary of the AMERICAN WELDING SOCIETY, and it should usually be found practicable to provide him with a copy, either on loan or permanently. Already Mr. Spraragen has the particulars of a matter of 100 translations of articles on welding and he is acquainted with the routine of making these available on loan, or, when the interest is sufficient, by mimeographing a supply of copies.

Individuals and companies are cordially invited to communicate with Mr. Spraragen or the writer if they desire to participate in this cooperative arrangement and indicate whether they are able to make translations, do mimeograph work or in other ways contribute to its effectiveness.

H. M. HOBART, Chairman

Translation

As indicated elsewhere in this issue of the JOURNAL in the Foreword prepared by Mr. H. M. Hobart, Chairman of the Fundamental Research Committee, this Committee in cooperation with the Welding Research Committee of Engineering Foundation, intends to make available translations of important articles dealing with foreign research. In order to make this service a success, cooperation is necessary on the part of a number of companies and individuals. A translation on the paper on "Strength of Machine Elements as Dependent on Their Shape," by August Thum and Wilhelm Bautz, from *Stahl und Eisen*, Vol. 55, No. 39, pp. 1025–1029, September 26, 1935, has been made available through the courtesy of one of the cooperating companies and extra copies have been prepared by another. A limited number are available in the office of the AMERICAN WELDING SOCIETY upon request.

Additional papers entitled "Krupp's Special Welding Method According to German Patent 567,094" by E. Beckmann, appearing in *Technische Mitteilungen Krupp*, No. 4, v. 3, August 1935, pp. 137–142, and "Influence of Welded Seams of a Highly Alloyed Welding Material on the Life of Boiler Plates," by C. Carius, appearing in *Technische Milteilungen Krupp*, No. 4, v. 3, August 1935, pp. 173–175, are also available in limited quantities.

School Attracts Welding Engineers from Diverse Industries

Twenty-six engineers from 8 states and 2 foreign countries, concerned with the arc welding of everything from plows to locomotives, are back at their duties packed with cost-cutting ideas after five days in lecture room and laboratory at Cleveland.

The December session of the special welding engineering course offered each month jointly by John Huntington Polytechnic Institute and The Lincoln Electric Company, Cleveland, Ohio, and just finished, brought together men of an unusually wide variety of interests. Included were representatives of machinery fabricators, railroad shops, oil refineries, structural fabricating shops, steel manufacturers, chemical plants, boiler and tank shops, pipe line contractors and job welding shops. These men were out to broaden their understanding of arc welding in all its phases.

Engineers from Washington to U. S. S. R. Get Welding Operation and Weld Inspection Instruction as Part of Their 5-Day Course in Cleveland

Under the tutelage of Mr. E. W. P. Smith, Welding Engineering Department, John Huntington Polytechnic Institute, Mr. Wilmer Stine, Research Engineer, Lincoln Electric, Prof. Fred L. Plummer, Case School of Applied Science and Mr. Arthur Madson, Welding Instructor, The Lincoln Electric Company, the engineers received a comprehensive picture of arc welding design and practice. Sessions were held in the mornings, afternoons and evenings for the five days.

One of the high-lights of the course was a demonstration of the use of polarized light for the study of stress concentrations in models of welded joints and machine parts.

The purpose of these courses, as outlined by Mr. A. F. Davis, Vice-President, Lincoln Electric, at a dinner meeting one night, is to simplify the men's problems of attaining those welding engineering goals which are so much easier to see than to reach. He cited specific examples of cost cutting achievements made possible.

Thermal Stresses in Welded Bars

At the request of one of the university workers on stresses in welds, a translation was made of an article on "Thermal Stresses in Welded Bars." The AMERICAN WELDING SOCIETY has two copies on file. The Society will be glad to lend these copies to any one interested.

Tentative Welding Program A. I. E. E. Winter Convention

The Winter Convention of the American Institute of Electrical Engineers will be held on January 28-31, 1936, in the Engineering Societies Building, New York, N. Y.

The program for the Electric Welding Demonstrations session on Thursday afternoon, the 30th, will be as follows:

H. M. Hobart, Presiding

Application of High-Speed Photography to the Study of Weld Phenomena, by H. A. Winne, General Electric Co.

Phenomena of the Flash Welding Arc, by W. E. Crawford, A. O. Smith Corp.

Demonstrations of the Accuracy of Ignitron Control, Engineers of the Westinghouse Electric & Mfg. Co.

There will also be a group of 10-minute addresses about Research as follows:

Prof. C. A. Adams—"American Welding Society and Research"

Dr. A. D. Flinn—"Engineering Foundation and Cooperative Welding Research"

Mr. F. M. Farmer, Chairman, A. I. E. E. Research Committee—"A. I. E. E. and Welding Research"

Mr. William Spraragen—"Laboratories, Libraries and Welding Research"

All members of the A. W. S. are cordially invited to attend.

EMPLOYMENT SERVICE BULLETIN

POSITION VACANT

V-66. We have an opening for good young metallurgist with a knowledge of modern Shielded Arc welding. Location Oklahoma City.

SERVICES AVAILABLE

A-226. Gas and Electric welder, steel worker and draftsman. Last place of employment up to November 1935, Colonial Sand & Gravel Company, Port Washington, L. I. Maintenance on dredge work, boiler and steel plate fabrication. Also formerly employed by the Vulcan Welding Co., Brooklyn.

Bound Volume Journal

The AMERICAN WELDING SOCIETY has made arrangements for members who wish to have their JOURNALS for 1935 bound in attractive, imitation black leather covers to do so by sending copies of the twelve issues to Russell-Rutter Company, Thirty-Third Street and Eighth Avenue, New York, N. Y., Att. Mr. Russell Lauben, Jr. A special reduced rate has been arranged at $1.75 per volume providing the issues of the JOURNAL are sent to the binder on or before February 15th. The bill for the binding and return postage will be sent direct from the Society's office.

American Institute of Steel Construction

This is to announce that F. H. Frankland has, as from January 1, 1936, been designated as Chief Engineer of the American Institute of Steel Construction.

Lee H. Miller was Chief Engineer of the Institute from its establishment in 1921 until his death in April 1933, at which time Mr. Frankland took over the duties of the Chief Engineer in addition to his other functions in executive charge of the Institute's district offices and technical service, being then designated Technical Director. Mr. Frankland is in charge of technical research and development, in addition to his other duties, and represents the Institute on numerous technical society committees concerned with structural steel manufacturing, design and construction.

Mr. Frankland joined the Institute in 1928, and was placed in charge of the organization and operation of the Institute's district offices and engineering service. Prior to that he was structural engineer for Dwight P. Robinson & Co. for four years; Vice-President and Chief Engineer of Bancroft-Jones Co., steel constructors, of Buffalo, for two years. Practiced in New York City as a consulting engineer on the design and construction of steel bridges and buildings for two years, after four years as partner in the Waddell firm of consulting bridge engineers, where Mr. Frankland was in charge of new business and preliminary designs.

SECTION ACTIVITIES

CHICAGO

Arrangement has been made with the Armour Institute of Technology for the holding of future meetings of the Chicago Section in Mission Hall, Armour Institute, 47 W. 33rd Street.

The subject of the December 27th meeting was "Flame Cutting and Machining." Mr. W. B. Browning of the Linde Air Products Co. was Chairman. The program included a lecture course "Metallurgy as Applied to Welding," by Jules Muller, Chicago Steel and Wire Company, and "Flame Cutting and Machining"; actual demonstrations of machine cutting and hand cutting with explanations of theory, practice and applications. Also effect of cutting on cut edge.

CLEVELAND

The second regular monthly meeting of the Cleveland Section was held at Cleveland Engineering Society, December 11th. Mr. R. A. Bull, Consulting Engineer, addressed the meeting on "High Tensile Steel Castings"; Mr. A. C. Denison, President, Fulton Foundry and Machine Co., spoke on "High Tensile Iron," and Mr. Albert Williams, Welding Engineer of the Wellman Engineering Co., spoke on "High Tensile Welding."

DETROIT

A joint session between the Detroit Section of the A. W. S. and the S. A. E. was held on Friday evening, January 17th, during the S. A. E. Annual Meeting in Detroit. Mr. C. L. Eksergian of the Budd Wheel Company was Chairman of this session. Mr. F. R. Hensel, of P. R. Mallory & Co., presented a paper on "Physical Chemistry of Arc Welding," and Mr. E. I. Larsen, P. R. Mallory & Co., presented a paper on "Fundamentals of Spot Welding."

NEW YORK

A joint meeting of the New York Section, A. W. S., and Power Division, A. S. M. E., will be held on January 21st in Room 501, Engineering Societies Building, on "The Rules for Welding in the New A. S. A. Code for Pressure Piping." A number of short addresses will be given by members of the Pressure Piping Code Committee and others who have been identified with the formulation of this Code. Following these, a general discussion of the new Code rules will be invited. Included among the speakers are such men as A. W. Moulder, Grinnell Company; A. M. Houser, The Crane Company; Alfred Iddles, United Engineers & Constructors, Inc., and E. R. Fish, Hartford Steam Boiler Insp. & Ins. Co.

A joint meeting of the New York Section, A. W. S., Metropolitan Section, A. S. C. E., and New York Section, American Water Works Assn., will be held on February 4th in Room 502, Engineering Societies Building. The subject will be "Steel Dams."

PHILADELPHIA

At the January 20th meeting of this Section Dr. George V. Slottman, Applied Engineering Department, Air Reduction Sales Co., will talk on "Hydro-Carbon Fuel Gases for Cutting."

The December 4th and 11th Special Lecture Course Meetings were well attended and on both evenings there was a good discussion after the presentation of the papers.

PITTSBURGH

At the January 15th meeting of the Pittsburgh Section Mr. Charles H. Jennings, Welding Engineer, Research Labs., Westinghouse Elec. & Mfg. Co., presented a paper on "Arc Welding Procedure Problems." This talk covered a number of the more important practical phases of welding and their relation to the welding engineer and workman. Among the subjects discussed were the weldability of low alloy steels, design problems in welding, methods of welding large structures and elimination of distortion in welded structures. Slides were used to illustrate the talk.

SAN FRANCISCO

At the December 13th meeting of the San Francisco Section a nominating committee was elected consisting of: G. R. Owens, General Electric Co., San Francisco, Chairman; J. LaForce, Linde Air Products Co., San Francisco; K. V. King, Standard Oil Co., San Francisco; Geo. H. Raitt, Steel Tank & Pipe Co., Berkeley; J. G. Bollinger, Air Reduction Sales Co., Berkeley.

The speaker of the evening was Professor Ward, Mechanical Engineer from the University of California, who gave a very interesting lecture on the subject "The Important Ingredients of Sound Welding Practice."

The Pacific Railway Club extended an invitation to the members of this Section to attend their January meeting held at Key System Auditorium, Oakland, Thursday evening, January 9th, at which the subject "Welding in Railroad Shops" was discussed by C. A. Daley, Maintenance of Way Eng., Air Reduction Sales Co., and Frank Longo, Supervisor of Welding, Southern Pacific General Shops.

American Welding Society Directors, 1935-36

President—J. J. Crowe, Air Reduction Sales Company, 100 Forrest St., Jersey City, N. J.

Senior Vice-President—E. R. Fish, The Hartford Steam Boiler Inspection & Insurance Co., Hartford, Conn.

Treasurer—C. A. McCune, Magnaflux Corporation, 25 West 43rd St., New York, N. Y.

Secretary—M. M. Kelly, AMERICAN WELDING SOCIETY, 33 West 39th St., New York, N. Y.

Divisional Vice-Presidents

New York & New England—A. G. Leake, The Leake & Nelson Company, Bridgeport, Conn.

Middle Eastern—W. W. Reddie, Westinghouse Elec. & Mfg. Co., E. Pittsburgh, Pa.

Middle Western—C. L. Eksergian, Budd Wheel Company, Detroit, Michigan.

Pacific Coast—T. C. Smith, General Petroleum Corp. of Cal., Los Angeles, Cal.

Southern—E. E. Dillman, Wyatt Metal & Boiler Works, Dallas, Texas.

Directors at Large

Term expires 1936

A. Vogel, General Electric Company, Schenectady, N. Y.

W. H. Gibb, Gibb-Lewis Company, 1331 Continental Illinois Bank Building, 231 South LaSalle Street, Chicago.

H. S. Smith, Union Carbide Company, 30 East 42nd Street, New York, N. Y.

W. C. Swift, American Brass Company, Waterbury, Conn.

J. C. Lincoln, R. F. D. No. 1, Box 140' Scottsdale, Arizona

E. A. Doyle,* Linde Air Products Company, 30 East 42nd St., New York, N. Y.

Term expires 1937

A. M. Candy, Hollup Corporation, 3357 West 47th Place, Chicago, Illinois

J. H. Deppeler, Metal & Thermit Corporation, 120 Broadway, New York, N. Y.

A. E. Gaynor, J. A. Roebling Sons Company, 107 Liberty St., New York, N. Y.

O. E. Hovey, Consulting Engineer, 71 Broadway, New York, N. Y.

L. S. Moisseiff, Consulting Engineer, 99 Wall Street, New York, N. Y.

F. P. McKibben,* Consulting Engineer, Fayetteville, Franklin Co., Pa.

Term expires 1938

C. A. Adams, Pierce Hall, Harvard University, Cambridge, Mass.

H. M. Hobart, General Electric Company, Schenectady, N. Y.

F. T. Llewellyn, United States Steel Company, 71 Broadway, New York, N. Y.

G. D. Spackman, Lukenweld, Incorporated, Coatesville, Pa.

H. L. R. Whitney, M. W. Kellogg Company, 225 Broadway, New York, N. Y.

D. S. Jacobus,* The Babcock & Wilcox Company, 85 Liberty Street, New York, N. Y.

Section Representatives

Boston—L. F. Jackson, Linde Air Products Co., 1017 Old South Bldg., Boston, Mass.

Chicago—C. J. McGregor, American Steel & Wire Co., 208 S. LaSalle St., Chicago, Ill.

Cleveland—A. E. Gibson, Wellman Engineering Co., 7000 Central Ave., Cleveland, Ohio

Detroit—Col. A. S. Douglass, Detroit Edison Co., 2000—2nd Avenue, Detroit, Mich.

Los Angeles—Frank Howard, Smith-Emery Co., 920 Santee St., Los Angeles, Calif.

New York—J. B. Tinnon, Metal & Thermit Corp., 120 Broadway, New York, N. Y.

N. New York—R. T. Gillette, General Electric Company, Schenectady, N. Y.

Philadelphia—R. D. Thomas, R. D. Thomas & Co., 401 N. Broad St., Philadelphia, Pa.

Pittsburgh—W. W. Reddie, Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

Portland—L. M. Pickett, Steel Tank & Pipe Co., P. O. Box 1899, Sta. F, Portland, Ore.

San Francisco—C. S. Smith, Linde Air Products Co., 114 Sansome St., San Francisco, Calif.

Milwaukee—Otto Voss, Allis-Chalmers Mfg. Co., West Allis, Wisconsin

Maryland—H. N. Boetcher, Consolidated Gas, Elec. Lt. & Power Co., Baltimore, Md.

* Junior Past-Presidents.

Safeguarding Your Service

Skilled maintenance men guard your telephone service day and night. As a result of their vigilance, both local and long distance calls go through more quickly and accurately.

IT IS easy to telephone, but there is nothing easy about giving you good telephone service. It takes many thousands of trained employees to do that.

A considerable part of this work is handled by the Central Office men. Their job is to safeguard service — to prevent trouble from getting a start.

They are constantly testing lines, circuits, switchboards and other equipment — working with outside repair men — performing the thousand and one tasks that keep things running right and prevent their going wrong. This work goes on twenty-four hours a day — every day in the year.

The "trouble shooters" of the Bell System work quickly, effectively because of careful training and long experience. Their loyalty, skill and resourcefulness are a priceless tradition of the telephone business.

It is no accident that your telephone goes along for so many months without trouble of any kind. The Bell System gives this country the most efficient, reliable telephone service in the world.

Bell Telephone System

Our Advertisers Are Supporting the Society